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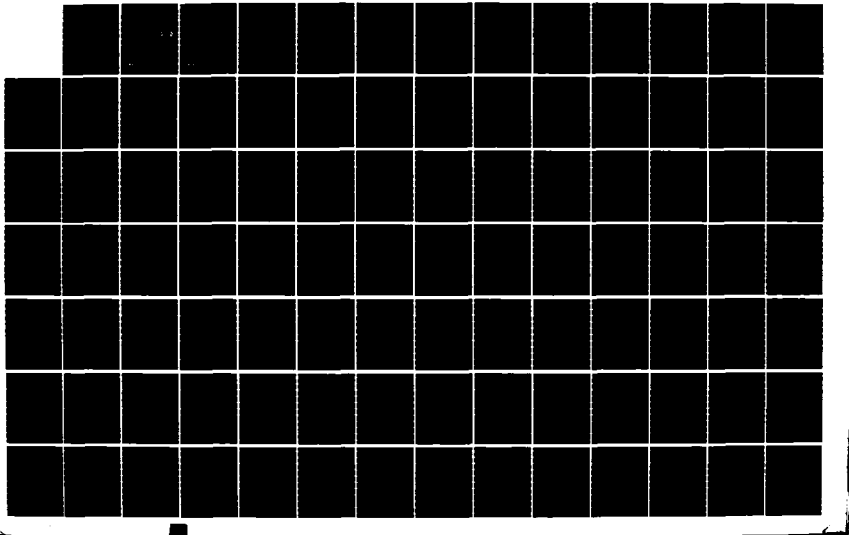

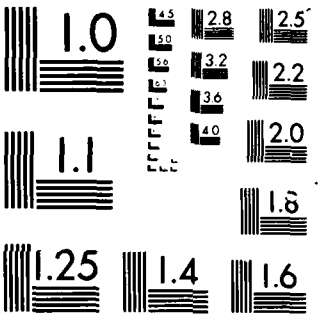

A RAND NOTE

THE RAND-ABEL™ PROGRAMMING LANGUAGE: Reference Manual

Norman Z. Shapiro, H. Edward Hall,
Robert H. Anderson, Mark LaCasse

October 1985

N-2367-NA

Prepared for

The Director of Net Assessment,
Office of the Secretary of Defense

Rand
1700 MAIN STREET
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This Note describes the RAND-ABEL programming language, which was designed to be suitable for (1) large rule-based systems, (2) war gaming and multiscenario sensitivity analysis, and (3) use by any of several governmental gaming and analysis organizations. RAND-ABEL is a preprocessor for the C programming language under the UNIX operating system, which makes RAND-ABEL quite portable across different computers. It is very fast in execution time when compared with other languages of similar readability. The RAND-ABEL language provides a number of unique capabilities. For example, it supports tables within the source code, for use as decision tables or to govern an iterative execution, and it is a strongly typed language, permitting certain kinds of errors in complex programs to be uncovered early. A related Rand publication, R-3274-NA, traces the evolution of RAND-ABEL, and discusses some of the requirements and principles underlying its design.

PREFACE

The RAND-ABEL™ programming language[1] was developed at The Rand Corporation for use in writing complex "agents" as part of a system for automated war gaming. The language was designed and implemented by Norman Z. Shapiro, H. Edward Hall, and Mark LaCasse for use by the Rand Strategy Assessment Center (RSAC). The RSAC and the work reported her are supported by the Director of Net Assessment in the Office of the Secretary of Defense under Contract MDA-903-85-C-0030.

RAND-ABEL is an operational language that is continuing to evolv This Note documents the RAND-ABEL language as its exists operationall in September 1985. A subsequent version of the language will be operational within a few months, and will be documented thereafter. That version will include interpretive features, sets, and a substantially expanded capability for executable tables within the source code.

The present Note is intended for programmers and applications specialists that will be writing in the RAND-ABEL language. It gives a somewhat terse but complete description of the language. It assumes that the reader is fluent in at least one high-level programming language (or better yet, several) and is familiar with the notation and concepts used to describe the formal syntax of programming languages. Others will find this reference manual useful after becoming familiar with RAND-ABEL by other means. The following document traces the evolution of RAND-ABEL, and discusses some of the requirements and principles underlying its design:

Shapiro, Norman Z., H. Edward Hall, Robert H. Anderson, and Mark LaCasse. *The RAND-ABEL™ Programming Language: History, Rationale, and Design*, The Rand Corporation, R-3274-NA. August 1985.

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[1]RAND-ABEL is a trademark of The Rand Corporation.

Inquiries and comments on this Note are welcome. They may be sent directly to the authors or to Paul K. Davis, director of the Rand Strategy Assessment Center.

SUMMARY

This reference manual describes the RAND-ABEL programming language. In designing the RAND-ABEL language, we determined that

- RAND-ABEL should be suitable for large, rule-based systems
  - It should lend itself to program development by multimember programming teams
  - It should be fairly easy to maintain
- RAND-ABEL should be suitable for war gaming and multiscenario sensitivity analysis
  - Domain-substantive RAND-ABEL rules should be readable by domain specialists who are not RAND-ABEL programmers, and the code should be self-documenting
  - RAND-ABEL should be efficient in execution
- RAND-ABEL should be suitable for use by any of several governmental gaming and analysis organizations
  - It should be transportable to various computers capable of hosting the UNIX operating system.

The RAND-ABEL language was designed for the specific requirements of the Rand Strategy Assessment Center (RSAC). RSAC is building a large system for automated and semi-automated war gaming in which separate models can represent U.S., Soviet, and third country behavior [Davis and Winnefeld, 1983; Shukiar, 1985]. RAND-ABEL is a preprocessor for the C programming language under the UNIX operating system, which makes RAND-ABEL quite portable across different computers. RAND-ABEL is very fast in execution time when compared with other languages of similar readability. We estimate that C language programs execute no more than three times faster than comparable ABEL programs.

In the RSAC environment, RAND-ABEL is used with a data dictionary, a data editor, and support for co-routines. This allows a flexible, hierarchical modeling system, allowing human teams to replace some of the models. Although designed for the RSAC, we anticipate that

RAND-ABEL will be of interest for other applications on UNIX systems requiring a highly readable language, fast performance, and early discovery of errors (for example, in the design of large rule-based models and simulations).

The RAND-ABEL language provides a number of unique capabilities. For example, RAND-ABEL supports tables within the source code, for use as decision tables or to govern an iterative execution. We find that table statements provide a much more succinct and readable alternative to long sequences of sentence-like rules typical of rule-based languages. When used as decision tables, RAND-ABEL tables correspond closely to the decision trees analysts and reviewers use in working out a logically complete argument. RAND-ABEL tables have a syntax that is inherently two-dimensional.

RAND-ABEL is a strongly typed language, permitting certain types of errors in complex programs to be uncovered early. Many of RAND-ABEL's features are derived from constructs in the C programming language.

ACKNOWLEDGMENTS

Jean LaCasse tested the RAND-ABEL Translator's robustness and diagnostics at various stages, helped debug some of the code, and wrote preliminary documentation.

Several other members of the RSAC staff have made valuable suggestions regarding RAND-ABEL syntax and requisite features. These include Steven Bankes, Arthur Bullock, Paul Davis, William Jones, Christe McMenomy, Ross Quinlan, and Herbert Shukiar.

We especially wish to acknowledge strong and continuing support for the development of the RAND-ABEL language by Paul Davis and Herbert Shukiar of the Rand Strategy Assessment Center (RSAC). Paul's stubborn refusal to be satisfied with anything less than our best effort at meeting RSAC's real needs, Herb's effective and knowledgeable guidance, and their allocation of resources to RAND-ABEL when its future was uncharted are responsible for RAND-ABEL's success to date.

CONTENTS

I. INTRODUCTION

OVERVIEW

RAND-ABEL is a computer programming language implemented on the UNIX[1] operating system. A program called the "RAND-ABEL Translator" compiles RAND-ABEL statements into a C program [Kernighan and Richie, 1978], which is in turn compiled and run.

RAND-ABEL was developed for use in the Rand Strategy Assessment Center (RSAC), to be used in the development of complex models. Six primary design goals guided the development of RAND-ABEL. RAND-ABEL is intended to be:

- Reasonably self-documenting. The RAND-ABEL code, by itself, should convey the meaning of a program.
- Understandable by English speakers familiar with the subject matter. Readers of the program should not need detailed programming knowledge to comprehend the program.
- Reasonably easy to learn and use by individuals with good analytic capability and modest programming skills. Analysts and application specialists with only some prior experience in a high-level programming language, such as FORTRAN, should be able to program effectively in RAND-ABEL without extensive training and study.
- Rapid in execution. Because RAND-ABEL was specially designed for building rule-based programs with many qualitative variables, it is important that these large programs be able to execute rapidly and efficiently.
- Portable across different types of computer hardware. RAND-ABEL and systems developed in it should not be unique to a single computer or a manufacturer's computers, but rather be portable across a range of minicomputers and powerful microcomputers.

[1]UNIX is a trademark of AT&T Bell Laboratories.

- Supportive of specialized RSAC needs, such as co-routines and tabular data, and well-suited to the creation of complex simulations by groups of developers.

Although the current version of RAND-ABEL is easy to learn for the simple programs most people work with, it requires a professional programmer to learn the intricacies of RAND-ABEL required to run the full RSAC simulation with all of its multiple coprocesses and interfaces. In its present form, RAND-ABEL is not as easy to use as we had expected. This shortcoming should be reduced with the imminent arrival of interpretive RAND-ABEL.

Prior to the development of RAND-ABEL, the Rand Strategy Assessment Center used the ROSIE language [Fain et al., 1981] for programming the Scenario Agent. The ROSIE program representing the Scenario Agent of the Mark II RSAC system is documented in Schwabe and Jamison, 1982. We found that RSAC programs executed in ROSIE orders of magnitude too slow for our future needs, which included operating large-scale simulations in a matter of minutes. Also, we sought special features (e.g., decision tables) that were not likely to be available in ROSIE. Therefore, RAND-ABEL was developed as a separate language.[2] Nevertheless, much of the form and style of the statements in RAND-ABEL derive from its ROSIE heritage. It was found that analysts were using only a portion of the features of ROSIE, so that RAND-ABEL is a simpler language.

The goals of speed in execution and portability were achieved by writing a RAND-ABEL compiler (called the RAND-ABEL Translator) that translates RAND-ABEL statements into statements in the C language. Since C and its host operating system, UNIX, are available on a wide selection of computers, RAND-ABEL becomes similarly portable. In addition, efficient C language compilers are available, thereby permitting the efficient compilation of RAND-ABEL statements through this two-step compilation process. As a result, RAND-ABEL is currently available on those computers running the UNIX 4.2bsd operating system

[2]The history, rationale, and design of RAND-ABEL is described in Shapiro et al., 1985.

and having a C language compiler. Moving RAND-ABEL to later versions of AT&T's UNIX system should be trivial.

RAND-ABEL is a strongly typed language; that is, the properties of all identifiers are declared before they are used. The RAND-ABEL compiler then uses these properties to test the validity of RAND-ABEL statements, so that certain types of errors (particularly control-related and data-related errors) may be caught at the earliest possible time.

The RAND-ABEL language contains a number of novel features. Perhaps the most novel construction in RAND-ABEL is the table statement; the following is valid RAND-ABEL code. (In this and other examples in this manual, RAND-ABEL keywords are printed in **boldface** to distinguish them from identifiers, constants, and comments chosen by the user to describe a particular application. Comments appear within square brackets.)

```
Table Deploy
    [This table initiates the deployment of assigned forces]

    qty   #-%  unit-type  unit-owner    to-area
    ====  ===  =========  ============  ======== .
     100    %  Troops     Denmark       CEur-1
     100    %  Troops     Netherlands   CEur-2
      25    %  Troops     FRG           CEur-3
     100    %  Troops     UK            CEur-4
     100    %  Troops     Belgium       CEur-5 .
```

All RAND-ABEL tables consist of column headings followed by rows containing data. In this example, there are five columns. The meaning of the top row of the table, as defined by the Deploy function, orders 100 percent of the troops "owned by" Denmark to deploy to axis 1 in CEur (the Central European theatre). The table calls the Deploy function five times (once for each row of data) with five parameters (bound to the entry in each column of the table).

The table statement is a powerful device, capable of both defining iterative processes and creating decision tables. Its syntax is fully two-dimensional. A function call or RAND-ABEL statement (possibly a compound statement) occurring immediately after the table keyword is called once for each row in the table, with the table's column headings

parsed and matched with function parameters or variables in the statement. The table statement was developed because tables of information were found to be a natural means of representation for the strategic analysts who are the primary users of the language.

A second noteworthy feature of RAND-ABEL is "declaration by example." All identifiers are declared by giving examples of their use, usually by an assignment statement:

Declare message **by example: Let** message **be** "I have Checkmate".

In this manner, the data type associated with an identifier is declared without requiring the use of a whole vocabulary (e.g., integer, real, character string, boolean, process, enumerated variable, array) that may not be meaningful to analysts who are not professional programmers. Furthermore, it is especially useful in rule-based systems with many ad hoc data types that otherwise would require names for strong typing (i.e., the data types to which enumerated variables belong).

RAND-ABEL also has a built-in set of functions to handle co-routines, and a "data dictionary" to coordinate external data references among program modules being developed independently. These language features are discussed in Sections IX and X of this Note.

NOTATIONAL CONVENTIONS

This Note presents the form and content of the RAND-ABEL programming language. In doing so, it must use a set of stylistic conventions to represent RAND-ABEL's form. These conventions must not be confused with the form of the RAND-ABEL syntax itself. The conventions used here are:

1. The RAND-ABEL language relies on a number of special keywords, or reserved words, which have a particular meaning. Appendix B contains a complete list of RAND-ABEL keywords. As mentioned earlier, in this manual RAND-ABEL keywords are printed in **boldface**, to distinguish them from other language constructs. In a RAND-ABEL program, these keywords must be written in

lower-case, with the first letter optionally upper-case. Therefore, the only two valid ways of writing a keyword are:

Declare, declare

This same case freedom does not extend to RAND-ABEL identifiers or character strings. The variable name "Country" is distinct from the (dangerously similar) name "country".

2. The syntax of RAND-ABEL is sometimes best described in terms of a set of syntactic categories, which themselves have a defined structure. These syntactic categories are represented by a word or phrase in italics, like *expression*. What is allowed in place of these categories is described in various sections of this manual. To find the definition of a category, look under that category in the index to this manual; it tells on which page that definition occurs.
3. To represent a set of options, one of which must be chosen, we use a single-spaced vertical stack of options. For example,

Trace **If.**
Function.

This notation means that the TRACE statement can take the form "**Trace If.**" or "**Trace Function.**".

4. Ellipses (i.e., "three dots" notation) are used to represent a sequence of zero or more RAND-ABEL constructs. For example,

statement . . . statement

means that zero or more *statements* can occur in a sequence. By extension, if a delimiter is used after the first occurrence and before the second occurrence with the three-dot notation in between, it means zero or more instances of that construct can occur in sequence, separated from each other by that delimiter. For example,

name , . . . , *name*

means that zero or more RAND-ABEL *names* can occur, separated by commas. When ONE or more occurrences are required, the above notation is sometimes used for convenience, with a note immediately below the syntax diagram stating that restriction.

5. The structure representing a particular RAND-ABEL language item is boxed, so that it is easily found. Rules specifying various restrictions and notes regarding this structure then follow. The particular syntactic category being (perhaps partially) defined is shown within the top border of the box. For example:

statement

If *Boolean-expression* **Then** *statement*

If *Boolean-expression* **Then** *statement* **Else** *statement*

II. NAMES, IDENTIFIERS, WHITE SPACE, AND COMMENTS

NAMES AND IDENTIFIERS

The entities of a RAND-ABEL program (variables, arrays, etc.) have names. Each is represented by a RAND-ABEL *identifier*, which is composed of a sequence of one or more of the following characters, without intervening spaces:

upper and lower case letters (A-Z, a-z)
digits (0-9)
the hyphen (-) (or its synonym, the underscore (_))
the number or pound sign (#)
the percent sign (%)
the plus sign (+)
the period (.)

Rules:

1. An identifier cannot end with a period.
2. An identifier cannot begin with a hyphen (-) or underscore (_).
3. An identifier cannot extend over a line of text (i.e., it cannot contain a carriage-return or line-feed character). It also cannot extend over a line of text by being hyphenated; the hyphen is treated just as any other character. (An identifier used as a column heading in a table statement is an exception to this rule. See the discussion of the table statement in Section VII.)
4. Upper-case letters are distinct from lower-case letters within identifiers; for example, the following identifiers represent different data items:

Country, country, COUNTRY, CounTry

5. A sequence of characters meeting the above restrictions, and intended as an identifier, must also not be recognizable as anything else, such as an integer or real number.

There is no restriction on length, other than the one-line limitation (Rule 3 above).

It should be noted that various text formatters in use at Rand and elsewhere interpret a period (.) in column 1 as a special formatting instruction, thereby causing problems if that is not intended. No RAND-ABEL statement begins with a period, but one could inadvertently appear in column 1 if an identifier begins with a period and a statement is continued onto a following line, causing an identifier to appear first on the succeeding line. It is safest not to start any identifier with a period.

Examples of valid RAND-ABEL identifiers:

```
country
Order-WTVD1-force-assignment
assumptions-re-Europe-On-Call
84flight#-2
```

An identifier having the form described above can also be an "identifier constant" as a member of the range of an enumerated data type. See the section on DATA TYPES for more information on enumerated data types.

A NOTE ON WHITE SPACE AND COMMENTS

RAND-ABEL statements and definitions consist of a set of words, some of them reserved keywords, some of them names (of variables, functions, etc.), and some of them unexecuted noise words or comments, made up by the program's author. The following rules hold in general in writing RAND-ABEL programs. Since RAND-ABEL is built upon the C language, the C conventions for program form should be followed in case of uncertainty.

Form Rules:

1. One or more spaces separating RAND-ABEL language constructs is considered to be "white space" that acts as a separator. Any comment enclosed by square brackets is also considered to be white space. Examples:

```
Let [the variable] Country be US.
Let[the variable]Country be US.
```

Both of these statements are equivalent to the statement:

```
Let Country be US.
```

White space occurring within a RAND-ABEL table header has special meaning; these rules do not strictly apply within it. See the sub-section "Table Statement" in Section VII for further information.

2. Carriage returns or line feeds are equivalent to space characters in creating white space; they have no other syntactic or semantic meaning. Example:

```
Declare [the function] plan by example:
    Let [the] plan of US,    [the originator]
                [in] 1984,   [the time period]
            [within] Europe  [the locale]
                be Defend-borders.
```

The above statement is equivalent to the statement:

```
Declare plan by example:
    Let plan of US, 1984, Europe be Defend-borders.
```

Spaces and other characters occurring within a quoted character string are taken literally, and are not considered white space as the term is being used in this discussion. For further

information about character strings, see Section III, or the syntax of character strings in the C language definition. Also, spaces are treated specially within table headers. See the discussion of the table statement for further information.

III. DATA TYPES

PRIMITIVE DATA TYPES

The RAND-ABEL language recognizes five distinct primitive data types. (In addition, the concept of enumerated data types and the ability to create pointers, functions, and arrays allow the user to construct an arbitrary number of additional data types; see below.) Every simple variable, value, and expression in the language is of one of these data types, either through explicit declaration or (in the case of expressions) by derivation from the form of constants and the prior declaration of variables used within them.

RAND-ABEL is a "strongly typed" language. That is, the data variables, values, or expressions on either side of an assignment statement, or binary operator, or used in place of a function's formal parameter, must agree. This strong typing is possible because all identifiers must be declared explicitly prior to use, thereby associating the identifier with a data type (or in the case of a structure or function, a sequence of data types). The RAND-ABEL translator will flag a statement as being in error if there is a mismatch of data types within the statement. (The only exception to the above statement relates to the various forms of numbers; it is explained below.)

The strong typing goes considerably deeper for constructed data types. Consider the following examples:

- A pointer is declared to point to an array of real numbers. The array has two indices: an integer and an enumerated data type. All assignments of this pointer to other data constructs must retain the characteristics of a two-dimensional array storing real numbers, indexed by an integer and an enumerated data type.
- A function is declared to return a process as its value, and has three formal parameters: a Boolean, a character string, and a pointer to an array having the characteristics given in

the previous example. All calls on this function must meet all these data type constraints, including the correct data types on the indices and stored values of the array pointed to by the third parameter.

The five built-in RAND-ABEL data types are:

Data Type	Description	Example(s)
1. Integer[a]	Whole number (with no decimal point explicitly represented)	1, -3567, 0
2. Real[b]	Decimal numeric value with decimal point explicitly positioned	5.34, -.0079, 0.0, 8. 6.02 E 23 (= 6.02 x 10**23) 4 E 3 (= 4000.0) 4 E -3 (= .004)
3. String[c]	String of zero or more characters delimited by quotation marks.	"Ally is not responsive." ""
4. Boolean	A logical data item which can only take on one of the two values: **Yes**, **No**	**Yes**, **No**
5. Process[d]	An identifying number for an RAND-ABEL co-process. Two reserved RAND-ABEL keywords represent the current process (**Self**) and its parent (**Parent**).	

[a] Integers are implemented in RAND-ABEL as the C language data type "long int", and are therefore subject to C restrictions for that data type.

[b] These numbers must have a decimal point contained in them, or use "E" (exponential) notation to represent a power of 10. If they use "E" notation, the number following the "E" must be a whole number. Since use of the E operator could be construed as part of an identifier (e.g., in 4E3 or even 4.0E3), it must be separated from its arguments by white space. Real numbers are implemented in RAND-ABEL as the C language data type "real", and are therefore subject to C restrictions for that data type.

[c] A string may be up to 256 characters in length, and may contain embedded carriage returns, line feeds, and so forth. The normal syntax and rules for character strings in the C language apply for character strings in RAND-ABEL.

[d] Co-processes are described in Section X.

ENUMERATED DATA TYPES

In addition to these primitive data types, additional data types may be constructed by the following mechanisms: enumerated data types, arrays, and pointers to various data constructs.

Enumerated data types may be constructed by declarations of the following type:

Declare country **by example**: **Let** country **be** {France, Germany}.

This defines a new data type, country, that can take on exactly two values: the identifiers France and Germany. These values will be called "identifier constants" within this document, and the data type (in this case, country) is sometimes called an enumerated variable.

Enumerated data types take on an explicit, finite-ordered list of values. The values are simple RAND-ABEL identifiers.

The only way an identifier constant is established is by the declaration of an enumerated variable including that identifier constant in its range (i.e., within the braces { }). The set of valid identifier constants is given in a declaration of the form:

Declare color **by example**: **Let** color **be** {Red, Green, Blue}.

In this example, "color" is a new data type, and "Red", "Green" and "Blue" are the (only) identifier constants in its range. (See Section V for a more complete description of declaration options.)

There is one reserved enumerated value that any enumerated data type can take on: **Unspecified**. This is not explicitly declared as a value. Note that it is NOT automatically assigned by RAND-ABEL to any variable, e.g., prior to an explicit assignment of a value to an enumerated-type variable. This value can be explicitly given to an enumerated-type variable through use of the keyword **Unspecified** (or its synonym "--") used in place of an identifier constant (e.g., in an assignment statement).

All enumerated data types are distinct from one another. Therefore, the value of one enumerated data type cannot be assigned to another (because this violates the "strict type checking" rule that only the same data types may be compared, assigned, or operated on together). Furthermore, all identifier constants are distinct from each other. For example, consider the two declarations:

```
Declare color by example:
    Let color be {Red, Green, Blue}.

Declare mood by example:
    Let mood be {Happy, Angry, Blue, Querulous}
```

If the two assignment statements were executed:

```
Let color be Blue.
Let mood  be Blue.
```

then not only is it NOT true that the value of color equals the value of mood (because the two Blues are distinct identifier constants), BUT THEY CAN'T EVEN BE COMPARED, as in:

```
If color = mood Then ...
```

because, as stated earlier, color and mood are two distinct data types, and therefore it is illegal to compare them.

IV. VALUES, EXPRESSIONS, AND OPERATORS

VALUES AND SIMPLE EXPRESSIONS

In a programming language, a value is informally considered to be a simple term that can be evaluated to yield either a storage location or the contents of that location. If it appears on the left-hand side of an assignment statement, its evaluation yields a location at which the assignment is to be made; if it appears on the right-hand side of an assignment, or elsewhere, its evaluation yields a data value. The description of the syntax of RAND-ABEL relies on the following categories of values and expressions, which are explained in this section:

Name	Informal Meaning
array-access	Access to the value stored at one of the cells in an array.
lvalue	A reference which can appear on the left-hand side of an assignment statement; that is, it designates a storage location at which a value is located.
unitparam	A value that is assigned to a parameter in a function call. A simple value, or else a parenthesized expression.
simple-expr	Any of the above values, or in addition a pointer to a function.
expression	A value, or a sequence of values related by operators.

The following tables give more precise definitions for these terms, nested to show the manner in which some definitions include others. For example, since the boxes defining *unitparam* and *lvalue* are contained within the box labelled *simple-expr*, all of the varieties of *unitparam*

and *lvalue* (defined by the contents of their boxes) can be used wherever a *simple-expr* is needed. Similarly, the various types of *array-access* can be used as whenever an *lvalue* is needed.

expression

Report from *function-invocation*

Evaluate *unitparam . . . unitparam*
with *format-spec unitparam . . . unitparam*

numeral variable-name
unary-operator expression
expression binary-operator expression

There is *array-access*
a *array-access*
an *array-access*

Describe *array-name*

simple-expr

Rules:

1. The **Report from** *function-invocation* expression calls the named function and returns as its value the value returned by the function. Example:

   Let message **be Report from** plan **of** US, 1984, Europe.

2. The **Evaluate** expression allows the RAND-ABEL writer to generate a string of characters (usable in further RAND-ABEL processing) from a sequence of arguments, each of them a *unitparam*. This string may then be used in subsequent RAND-ABEL statements--for example, as an argument to a function that requires a string as one of its parameters. The *format-spec* is a string of characters that can control the formatting of the resultant string; the syntax and options available for a *format-spec* are described in the subsection "Input/Output" in Section VII. Example:

```
Perform data-logging
    using Evaluate "The ally of" country "is"
                   (ally of country)
    as message.
```

In the above example, blanks are not required within the character strings to prevent the value of country from running into "The ally of" and "is" because the default print format for an enumerated variable contains prefix and postfix blanks. (See "Default Output Formats" in Section VII.)

3. The expression of the form *numeral variable-name* is a restricted form of implied multiplication. For example, one might use the phrase

```
3 kilometers
```

in a place where distance in meters is required; assuming the variable named "kilometers" had the value 1000, one would obtain the desired result. (This is a dangerous construction and should only be used under highly controlled circumstances.)

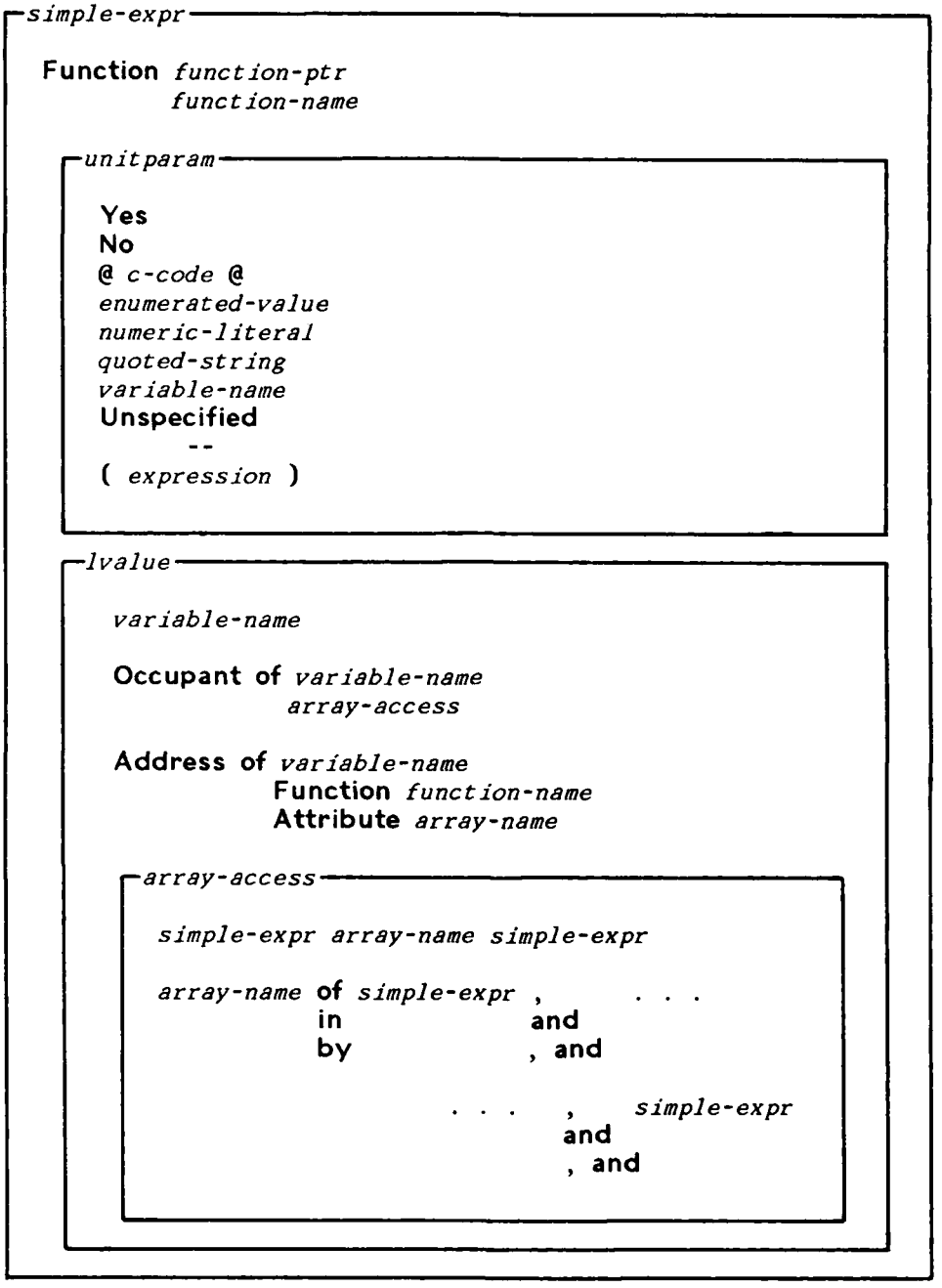
4. **There is** ... evaluates to **Yes** or **No** depending on whether the named array element has a stored value within an erasable array. (If the array has not been mentioned in a **Make Erasable** or **Make Semi-erasable** statement, it is an error.) Example:

```
If There is a border of Iran, Syria
Then Perform relative-strength-test using
        Iran as country_1 and
        Syria as country_2.
```

5. **Describe** *array-name* returns a character string that describes all the combinations of indices and their corresponding values for which the array is presently defined. It is used primarily for list-stored (i.e., **Erasable**) arrays (see "To Declare an Array...") and for debugging. However, it will work for all variables and arrays, regardless of method of storage. A variable is equivalent to an array with zero indices (a "0-ary

array"). The separate linguistic construct called "variable" is only used for convenience in referring to this common construction.

A *simple-expr* is defined by the following nested set of tables. The nesting again shows that certain terms are contained within the definitions of others. For example, a *unitparam* is one valid type of *simple-expr*, so any of the methods of constructing a *unitparam* can be used wherever a *simple-expr* is needed.


simple-expr
Function function-ptr
function-name
unitparam
Yes
No
@ c-code @
enumerated-value
numeric-literal
quoted-string
variable-name
Unspecified
--
(expression)
lvalue
variable-name
Occupant of variable-name
array-access
Address of variable-name
Function function-name
Attribute array-name
array-access
simple-expr array-name simple-expr
array-name of simple-expr , . . .
in and
by , and
. . . , simple-expr
and
, and

Rules:

1. The **Function** keyword, followed by the name of, or a pointer to, a RAND-ABEL function returns as its value the address of that named function, or the address of the function pointer referred to by the *function-ptr*. This returned value is of type pointer.
2. The "@" sign provides an escape to C code; see the C statement description in Section VIII for more information.
3. "--" is a synonym for the keyword **Unspecified**, which is used in conjunction with enumerated data types. (See the discussion of enumerated data types in Section III.)
4. The *variable-name* or *array-access* following the keywords **Occupant of** must be of data type pointer. The clause returns the contents of the storage location pointed at by that pointer.
5. The **Address of** clause yields a value of type pointer. For example:

   Address of Attribute country-array

   returns a pointer to the array named "country-array".
6. The first type of array access:

   simple-expr array-name simple-expr

   is used only for arrays with two indices. To be accessed in this infix manner, with the array name appearing between the indices, the array must have been declared in that same manner, as in:

   Declare larger-than **by example**:
   Let Iran larger-than Iraq **be Yes**.

Arrays declared in an infix manner must always be accessed in an infix manner. The second, "prefix", form of array access can be used with any number of indices (including two), and similarly must be declared using the prefix form:

```
Declare between by example:
    Let between of Canada, US, Mexico be Yes.
```

Arrays declared in a prefix manner must always be accessed in a prefix manner.

OPERATORS

The operators used to construct expressions can be categorized as numeric operators, comparison operators (providing equality and inequality tests), logical operators (yielding a **Yes** or **No** result), and string operators. Each of these categories is described below. In each case, we list a "preferred form" for representing these operators, to create as much consistency and readability in RAND-ABEL programs as possible.

Numeric Operators

Mathematical Notation (Preferred Form)	"English-like" Notation	Meaning
+	**plus**	Addition
-	**minus**	Subtraction
*	**times**	Multiplication
/	**divided by**	Division
	modulo	Modulo
-	**negative**	unary "-" sign

When an integer variable accepts the result of the division of two integers, the result will be truncated toward zero to an integer. Examples:

73/10 evaluates to the value 7
-73/10 evaluates to the value -7

Division by zero results in a run-time error.

These operators can yield floating point exceptions (i.e., error conditions) in a machine-dependent manner.

The modulo operator returns the remainder upon division. Example:

23 **modulo** 8 is 7.

The modulo operator requires integer arguments.

Only integer and real data types may be used as arguments for these operators. (Exception: the more stringent requirement for modulo arguments mentioned above.)

Comparison Operators

Comparison operators are categorized below as "equality" or "inequality" type operators. All comparison operators yield a value that is Boolean. One of the operands to these comparison operators can have an ambiguous data type, IF that ambiguity can be resolved by the requirement of consistency with the other operand's data type. RAND-ABEL does not, however, accept two operands of ambiguous data type, and attempt to resolve the mutual ambiguity. (Ambiguity can arise from a value such as the enumerated constant Blue, if more than one enumerated data type contains this constant in its range.)

Equality Tests

Mathematical Notation (Preferred Form)	"English-like" Notation	Meaning
=	**is**	Is equal to
~=	**is not** **are not**	Is not equal to

Both arguments to these operators must have the same type (with one exception: an integer appearing where a real number is needed is interpreted as a real number for that purpose).

Two operands from any one data type may be compared using these equality operators.

Two strings are equal only if they have the same length (including possibly zero length--i.e., the null string), and at each respective character position, their corresponding characters are equal. (Upper case and lower case versions of a character are treated as different characters in this test.)

Two enumerated values are equal only if they are represented by the same identifier constant, and are in the range of the same (enumerated) data type. The reserved word **Unspecified** is equal to **Unspecified** for the same data type.

It is an error if two enumerated values are compared that belong to different (enumerated) data types.

Inequality Tests

Mathematical Notation (Preferred Form)	"English-like" Notation	Meaning
>=	**is at least**	Greater than or equal to
<=	**is at most**	Less than or equal to
>	**is greater than**	Greater than
<	**is less than**	Less than

Both arguments to these operators must have the same type (with one exception: an integer appearing where a real number is needed is interpreted as a real number for that purpose).

The following data types may be compared using the inequality operators: integer, real, string, enumerated. Note that Boolean data types *CANNOT* be compared using these operators.

Integer and real data types compare according to their values.

Strings a and b compare as follows. (In comparing two individual characters, the collating sequence is used for the individual computer on which RAND-ABEL resides; this test is therefore implementation dependent.)

a. If a and b are both the null string, they are equal.
b. If one of them is the null string and the other is not, then the null string is less than the other.
c. Otherwise, compare strings a and b character-by-character; if each of these comparisons is **Yes** (i.e., true) at the time the end of one of the strings is reached, but the other string still has additional characters, then the shorter string is less than the longer one.
d. Otherwise, compare strings a and b character-by-character; if each of these comparisons is **Yes** (i.e., true) up to character position k, but is **No** (i.e., false) at character position k + 1, then if string a's character in position k + 1 is less than, or greater than, string b's character in position k + 1, then string a is less than, or greater than (respectively) string b.

Enumerated values compare with the inequality operators according to the following rules:

a. If either or both values is **Unspecified** (or its synonym "--"), then the result is **No**.
b. If the values belong to different (enumerated) data types, it is an error.
c. Identifier constant C1 is less than identifier constant C2 if and only if C1 appears before C2 in the sequence of identifiers defining the range of their common (enumerated) data type. If they are the same identifier within this data type, they are equal.

Logical Operators

Logical operators are used to combine two different Boolean operands--that is, ones taking the values **Yes** or **No**--to yield a new Boolean value. For example, a RAND-ABEL program might require the logic:

> **If** agreement **and** (Red-violates **or** Blue-violates)
> **Then Let** agreement **be No**.

The assignment of the value **No** to the variable "agreement" will take place only if the existing value of agreement is **Yes**, and in addition either "Red-violates" or "Blue-violates" (or both) is **Yes**.

Mathematical Notation	"English-like" Notation (Preferred Form)	Meaning
&	**and**	Logical "and"
|	**or**	Logical "or"
~	**not**	(unary) Logical "not"

The meanings of these operators are given in the following table:

a	b	not a	a and b	a or b
yes	yes	no	yes	yes
yes	no	no	no	yes
no	yes	yes	no	yes
no	no	yes	no	no

The logical operators require Boolean values (that is, **Yes** or **No**) as their arguments, and return a Boolean value as the result.

String Operator

The single string operator concatenates two strings to yield one resulting string. Concatenation may be used, for example, in the creation of tailored messages, as in:

Let outstr **be** "WARNING: " **$** message **$** " PLEASE RESPOND (Y/N): ".

In this example, the string variable "outstr" receives a string containing a variable "message", along with standard prefix and suffix strings.

Mathematical Notation (Preferred Form)	"English-like" Notation	Meaning
$	**concatenated with**	Concatenation

Only string values may be concatenated together. The result is a string consisting of the first string followed by the second string.

Example: "This is " **$** "a test."
and
"This is "**$**"a test."
and
"This is " **concatenated with** "a test."
are all equivalent to:
"This is a test."

Whenever there is any ambiguity or uncertainty, parentheses should be used to specify the order in which operators should be applied within an expression. When more than one operator is used in a sequence, precedence relations are used to resolve the order. Operators with higher precedence are performed first; within the same precedence, operators are performed within the expression from left to right. Operators of the same precedence associate to the left. For example,

(a & b & c) = ((a & b) & c).

The following table gives the precedence of RAND-ABEL operators. Operators in the same row are of equal precedence.

Highest precedence:	~ (**not**)			- (unary)
	*	/		**modulo**
	+	-		
	<	>	<=	>=
	=	~=		
	& (**and**)			
Lowest precedence:	| (**or**)			

V. DECLARATIONS

TO DECLARE A VARIABLE

declaration

Declare *variable-name* **by example:**

Let *variable-name* **be** *expression*.
{ *name* . . . *name* } .
{ *name* , . . . , *name* }.

Rules:

1. The type of the variable becomes the same as the type of the expression.
2. The type of the expression must be uniquely determinable at the time the statement is encountered. (For example, if the same enumerated value appears in the range of several enumerated data types, then it may not be used in an assignment within a declaration.)
3. The form { *name* . . . *name* } (with or without the optional commas as separators) creates an enumerated data type, and declares the specific values that variable can acquire (in addition to the special enumerated value **Unspecified**), with each value an identifier constant. Examples:

```
Declare troop-strength by example:
    Let troop-strength be 10000.

Declare force-ratio by example:
    Let force-ratio be 5.8.

Declare message by example:
    Let message be "Help!".

Declare agreement by example:
    Let agreement be Yes.
```

```
Declare current-force-test by example:
    Let current-force-test be
                    Address of Function calc1.

Declare alliance by example:
    Let alliance be {France, Germany, Spain}.
```

The spatial alignment of these statements is not important; they are aligned here by variable name merely for ease in reading.

TO DECLARE AN ARRAY; MAKE AND ERASE STATEMENTS FOR ARRAYS

Array Declarations

Arrays are declared and referenced in two possible ways: infix and prefix. "Infix" refers to placing the name of the array between its two indices; "prefix" means placing the array name before its list of indices.

If an array has exactly two indices, it may be declared in an infix manner; if it is, it must then always be referenced in the same infix manner. All arrays may be declared (and then necessarily referenced) in a prefix manner.

Note that a one-dimensional array, indexed by the smallest positive integers (1, 2, 3, ...), may be called a "vector" in other computer languages. A two-dimensional RAND-ABEL array indexed by the smallest positive integers corresponds with the term "matrix" in other computer languages.

The syntax diagrams below show the two different ways of declaring a RAND-ABEL array.

Prefix form:

declaration

Declare *array-name* **by example:**

Let *array-name* **of** *simple-expr* **,** . . .
in **and**
by **, and**

. . . **,** *simple-expr*
and
, and

be *expression*.
{ *name* . . . *name* }.
{ *name* , . . . , *name* }.

Infix form:

declaration

Declare *array-name* **by example:**

Let *simple-expr array-name simple-expr*

be *expression*.
{ *name* . . . *name* }.
{ *name* , . . . , *name* }.

Rules:

1. In the first (prefix) form there must be at least one *simple-expr*.
2. The second (infix) form is used only for arrays with two indices, as an option. Such an "infix array" is a separate data type, and must always be accessed as an infix array.
3. The type of the array is the type of the *expression*, which must be determinable at the time the statement is encountered.

4. Arrays can have one or more indices. (Arrays with zero indices are equivalent to variables.)
5. The *simple-exprs* that are used to index the array must be either of type integer or enumerated.
6. If any index is of type integer, it is designated by a single integer constant, n, in place of *simple-expr*. This index can then take on the integral values 0...n . Note that index n means that the index can take on n + 1 distinct values.
7. The form { *name* . . . *name* } (with or without the optional commas as separators) creates an array of enumerated data type, and declares the specific values that variable can acquire (in addition to the special enumerated value **Unspecified**), each value being an identifier constant. Examples:

Prefix array with integer indices and enumerated value:

```
Declare chessboard-square by example:
    Let chessboard-square of 7 and 7 be
        {king, queen, knight, bishop, rook, pawn, empty}.
```

Infix array with enumerated indices and Boolean value:

```
Declare Borders-on by example:
    Let US Borders-on Canada be Yes.
```

Infix array with enumerated indices and integer value:

```
Declare Length-of-border-with by example:
    Let US Length-of-border-with Canada be 5000 [km].
```

Erasable Arrays

There are times when selected values of an indexed array are to be stored and retrieved, but it is wasteful or impossible to allocate storage for all possible array values. For example, if the array "posture" takes four indices--a country (one of 50 enumerated values), a "readiness index" (one of 20 integers), an opponent country (one of 50 enumerated values), and a morale factor (one of 10 integers)--then array storage must be set aside for 50 x 20 x 50 x 10 values, or 500,000 locations. Only a small fraction of these might be used in practice. Arrays having only a small fraction of their values set are commonly referred to as "sparse arrays".

Sparse arrays may be stored in list structures, rather than arrays. List structures require storage space proportional to the number of cells used, not the number of potential cells. However, access to array cells in a list-stored array is slower than direct indexed access to an explicitly stored array.

In RAND-ABEL, sparse (i.e., list structured) storage of an array is requested through the **Make** statement:

statement

Make *array-name* **Erasable.**
Unerasable.
Semi-erasable.

Rules:

1. The **Make** statement must immediately follow the **Declare** statement for the array.
2. The **Erasable** option instructs RAND-ABEL to store the named array in a list structure, as a sparse array. Attempted access of an **Erasable** array element before it is set is a run-time detectable error.
3. The **Unerasable** option instructs RAND-ABEL to store the named array as an explicit indexed array (i.e., as arrays are stored in the C language). Access of an **Unerasable** array element before it is set is not detected, and can result in indeterminate (and therefore highly dangerous) results.
4. The **Semi-erasable** option is used for debugging. The array will be list stored, and the "**There is**" expression will be available for it (see below), but the **Erase** statement (described below) will not be available for it. For a **Semi-erasable** array, access of an array element before it is set is a run-time detectable error; this option is therefore useful in detecting errors in programs during their development.

If no **Make** statement is given for an array, RAND-ABEL determines the storage mode for the array based on its size and available storage space. This decision could vary between runs of the RAND-ABEL Translator.

The storage method RAND-ABEL uses for an array has only three effects detectable by the user:

1. The speed of array accesses can vary; for programs heavily dependent on arrays, this could affect program efficiency.
2. For list-stored arrays, attempted access of an array element before it is set is a run-time detectable error; for traditionally stored arrays, the error is not detected and an indeterminate value is accessed.
3. Array elements in a list-stored array may be "erased" and the storage thereby reclaimed. This option is not available for traditionally stored arrays. (Since this is a main operational difference between list-stored and traditionally-stored arrays, the keywords **Erasable** and **Unerasable** are used in the **Make** statement to distinguish between list storage and traditional storage, respectively.)

Erasure of all elements, or a selected element, of a list-stored array is accomplished with the **Erase** statement:

statement

Erase *array-name*.
array-access.

Rules:

1. Only arrays that have been made **Erasable** can be used in conjunction with the **Erase** statement.
2. If an *array-name* is given, all currently stored elements of that array are erased, and the storage reclaimed.
3. If an *array-access* is given, accessing an individual element of the array, then only that element is erased, and the storage reclaimed.

A Boolean *expression* is available for testing the existence of array elements in **Erasable** arrays:

There is a *array-access*.
an

See the section "Values, Operators, and Expressions" for a description of the operation of the **There is** expression.

TO DECLARE A FUNCTION

Every function that is used must be declared. Every function either always returns a value, or never returns a value. The function declaration indicates which of these cases applies, as well as the data type of the arguments and value returned, if any.

declaration

Declare *func-name* **by example:**

Let *expression* **be Report from** *named-function-call*.
Perform *named-function-call*.

Rules:

1. The first form must be used when the function returns a value. The type of the *expression* must be the same as the type of value returned by the function. The type of the *expression* must be determinable at the time this statement is executed.
2. The second form is used only when a function does not return a value.
3. A function must be declared before it is defined, and it must be defined before any use. Section VI discusses function definitions.

A *named-function-call* is one that explicitly uses the function name to invoke it, not a pointer to that function. Section VI describes the *named-function-call*.

Examples:

```
Declare select-country by example:
    Let France be Report from
          select-country using alliance as range
                          and strength as criterion.

Declare force-calc by example::
    Let 5.0 be Report from force-calc using
                          France as country.

Declare validity-check by example:
Perform validity-check.
```

VI. FUNCTIONS

DEFINING A FUNCTION

function-definition

Define *func-name* : *declaration* . . .
declaration
statement . . .
statement
End.

A *declaration* is any of the declaration types (starting with the keyword **Declare**) listed in Section V.

If the function returns a value, at least one of the statements within the function definition must be "**Exit Reporting** *simple-expr*". Moreover, one such statement must be reached during execution of the function, otherwise a run-time error will occur.

If the function does not return a value, it is exited either by an explicit **Exit** statement, or else by "falling through" the *statement*s to the **End** statement.

Examples:

```
Define Timed-wakeup:
    If Time is at least Time-to-wake of (Command-ID of self)
    Then
    { Record "Starting move at maximum time = " Time ".".
      Exit Reporting Yes.
    }
    Else Exit Reporting No.
End.
```

```
Define Next-move:
   Declare piece by example: Let piece be bishop.
   Let piece be whites-last-move-piece.
   Let y     be col-location of piece.
   Let x     be row-location of piece.
   If piece = pawn
   Then
   { If (Occupant of y   and x+1) = empty and
        (Occupant of y+1 and x+1) = empty and
        (Occupant of y-1 and x+1) = empty
     Then
     { Let row-location of piece be x+1.
       Exit Reporting "Done."
     }
   [ Place other piece moves here as they are
     programmed. ]
   }
   Else Exit Reporting "Can't handle."
End.
```

Note that in the above example, the scope of certain variables such as x and y is global (i.e., externally declared in the Data Dictionary outside of the function definition).

NAMED FUNCTION CALLS AND FUNCTION INVOCATIONS

A *named-function-call* is an invocation of a function in which the name of the function appears explicitly. It is required, for example, as part of the declaration of that function (which announced the names and data types of its arguments, and the type of its returned value, if any).

named-function-call

func-name

func-name **using** *expression* **as** *param-name* , . . .
for **and**
, and

. . . , *expression* **as** *param-name*
and **for**
, and

Rules:

1. In a *named-function-call*, the *func-name* must be given explicitly; a pointer to a function is not allowed in this case.
2. When used as an example in a function declaration, the types of each *expression* must be determinable at the time the declaration is encountered.

By contrast, a *function-invocation* has the same form as a *named-function-call*, but it can have a pointer to a function in place of an explicit function name:

function-invocation

named-function-call

func-ptr

func-ptr **using** *expression* **as** *param-name* , . . .
for **and**
, and

. . . , *expression* **as** *param-name*
and **for**
, and

When a function does not return a value, it is invoked through the statement

Perform *function-invocation*.

When a function returns a value, it is accessed via the expression

Report from *function-invocation*.

Examples:

```
Let message be Report from next-move
          using pawn as whites-last-move-piece.

If Report from Timed-wakeup
        using now as time is Yes
Then Perform Work.
Else Perform Error-handler.
```

VII. RAND-ABEL STATEMENTS

Statements are used in RAND-ABEL to define the operation of a function. (Several statements can also occur at the "top level" in RAND-ABEL outside of a function definition to set the global context in which other statements will operate: They are declarations, the Data Dictionary (see Section IX), the C statement, and the Trace and Untrace statements.)

The various forms of RAND-ABEL statements are described below within the following categories:

Assignment
Conditional execution
Repetitive execution
Functions: invoking and exiting
Input/output
Compound and null statements
Table statement

All RAND-ABEL statements begin with a keyword which uniquely identifies the statement type. In general, all RAND-ABEL statements end with a period; the only exceptions are compound, conditional, and repetitive statements whose form has an embedded *statement* as the last entity within the form. In those cases, the period ending the embedded *statement* becomes the statement delimiter.

ASSIGNMENT

Assignment statements are used to store a value in the location specified by either a variable or an array element.

statement

Let *lvalue* **be** *expression*.
pointer

Increase *lvalue* **by** *expression*.
Decrease
Multiply
Divide

Rule: The (data) types of the terms on the left-hand side and right-hand side of the assignment statement must match.

Two exceptions:

1. If a real number is required by the left-hand side, then if the value of the *expression* is integer, that integer is coerced into a real number for the purpose of this statement.
2. The right-hand side can be an enumerated identifier constant of ambiguous data type if that ambiguity is resolved by the type of the *lvalue* or *pointer* on the left-hand side.

The terms *lvalue* and *expression* are defined in Section IV. In general, an *lvalue* is what can normally occur on the left-hand side of an assignment statement: namely, a term giving the address of a named storage location, not a pure value.

Examples:

Let gross-profit **be** gross-sales - cost-of-sales.

Let force-ratio **be Report from** force-calc
using France **as** side-1 **and** Yugoslavia **as** side-2.

Decrease force-ratio **by** 2.5.

CONDITIONAL EXECUTION

Conditional execution is controlled by the **If** statement. It allows certain RAND-ABEL statements to be executed only if certain conditions are true, or are false.

statement

If *Boolean-expression* **Then** *statement*

If *Boolean-expression* **Then** *statement* **Else** *statement*

Rules:

1. The *Boolean-expression* is any expression that evaluates to type Boolean--i.e., that takes on values **Yes** and **No**.
2. If the *Boolean-expression* evaluates to **Yes**, then the first *statement* is executed.
3. If the *Boolean-expression* evaluates to **No** and the **Else** clause is present, the *statement* following the **Else** keyword is executed. If the *Boolean-expression* is **No** and no **Else** clause is present, no action is taken.
4. As is normal programming language practice, if conditional statements are nested, an **Else** clause is attached to the nearest previous **If** clause that does not yet have an **Else** clause attached. If one needs a null **If** or **Else** clause to keep the logic straight, use the RAND-ABEL null statement, consisting of just a period, as in:

If king-unchecked **Then**. **Else Perform** Think.

or

If king-in-check **Then Perform** Think. **Else**.

This statement is not delimited by a period, for reasons given at the beginning of this section: the last *statement* embedded within the **If** statement will contain its own delimiter.

Either *statement* can of course be a compound statement (that is, one or more *declaration*s and *statement*s contained within "{" and "}" braces) thereby allowing any needed complexity in logic to be stated in the **Then** or **Else** clauses.

Example:

```
If user-response = "Y" or user-response = "YES"
Then
{ Perform Recalculation.
  Print   "Calculation Completed.  More? (Y/N): "
  Let user-response be Report from query-user.
}
Else If user-response = "N" or user-response = "NO"
     Then
     { Print "No action taken.  More? (Y/N): "
       Let user-response be Report from query-user.
     }
     Else If  user-response = "?"
          Then Perform Help-function.
          Else
          { Print "Your response not understood."
            Perform Help-function.
          }
```

Note that If ... Then rules can also be formed using the table statement.

REPETITIVE EXECUTION

The RAND-ABEL **For** and **While** statements allow one or more statements to be executed repetitively--that is, zero or more times, depending on the controlling variable or expression.

statement

For *variable* : *statement*

While *Boolean-expression* : *statement*

Rules:

1. In the first form, the *variable* must be of the enumerated data type. The *statement* is executed once for each identifier constant in the range of the *variable*, with the *variable* bound in turn to each identifier constant, in the order in which the identifier constants are declared as being the range of the enumerated data type. Examples:

```
Declare alliance-members by example:
    Let alliance-members be
                    {France, Germany, Spain}.

For alliance-members Perform Force-calc.


For each-country (US or UK or FRG or Belgium):
{
      Let Membership of each-country be Nato.
      Let Side       of each-country be Blue.
}
```

2. In the **While** form, the *Boolean-expression* is evaluated. If its value is **Yes**, the statement is executed; if the value is **No**, no further action is taken. If the statement executes, the *Boolean-expression* is then reevaluated, and if **Yes** the statement is reexecuted. This sequence continues until the value of the *Boolean-expression* becomes **No**. Example:

```
Let k be 3.
While k>0: {
                Print resultsfile k.
                Decrease k by 1.
           }
```

...leads to the following records sent to the resultsfile:

```
3
2
1
```

The following two RAND-ABEL statements are used within a repetitive execution to change the flow of the program's logic:

statement

Continue.

Break.

Rules:

1. Within a repetitive execution, the **Continue** statement acts as completion of the current repetition, and control passes to the next repetition of the loop, if any.
2. The **Break** statement acts as completion of all repetitions of the loop, and control passes to the statement following the repetitive statement.
3. In both cases, control returns to the most immediately inclusive **Table**, **For** or **While** statement. That is, to the innermost repetitive statement if they are nested. Examples:

```
Let k be 3.
While k>0:
{
    If k=1 Then Break.
    Else {Print resultsfile k. Decrease k by 1.}
}
```

...leads to the sequence of records in resultsfile:

```
3
2
```

```
Let k be 3.
While k>0:
{
    If k=2 Then Continue.
    Else {Print resultsfile k. Decrease k by 1.}
}
```

...leads to one printed record in resultsfile:

```
3
```

...followed by an infinite loop, with k=2 and the **While** statement repetitively executing with no effects.

Repetitive execution can also be achieved by the RAND-ABEL table statement. This special RAND-ABEL statement is described in the following section.

TABLE STATEMENT

The **Table** statement is the most powerful statement in RAND-ABEL. It can be used to call a function repeatedly, with different arguments, or as a decision table. It is an example of a statement with a two-dimensional syntax; the spatial layout of the table-header is important in determining the meaning of the table statement.

statement

Table *func-name*
compound-statement

table-header.

table-body.

Basically, the table statement allows the named function or the *compound-statement* to be executed once for each row of data in the *table-body*. If the table statement contains a named function, the columns of data within the *table-body* are matched up with the function's formal parameters by means of the column headings within the *table-header*; if the table statement contains a *compound-statement*, the local variables declared within the highest level block of that compound statement are matched with the columns of data within the *table-body* by means of the column headings within the *table-header*.

The concept and power of the table statement is best illustrated by example. The following RAND-ABEL table uses the function "Deploy". It is an expanded version of the example shown in Section I of this Note.

Table Deploy
[This table initiates the deployment of assigned forces to the Central European theater]

qty	#-%	unit-type	unit-owner	assigned-to
			in-area	to-area
100	%	Troops	Denmark	CEur
			All	CEur-1
100	%	Troops	Netherlands	CEur
			All	CEur-2
25	%	Troops	FRG	CEur
			All	CEur-3
100	%	Troops	UK	CEur
			All	CEur-4
100	%	Troops	Belgium	CEur
			All	CEur-5

This table statement causes the function Deploy to be called five times, once for each row of the *table-body*. (Each row has seven entries, the last two being "folded over" so that they appear underneath the columns labelled "unit-owner" and "assigned-to".)

Another important use of a table statement is as a decision table. It is standard practice (although not required by the syntax of the table statement) to use a slash (/) within the table header to separate the conditions from the action to be taken. (Formerly, a vertical bar (|) was commonly used, but this symbol has taken on a new meaning within a table header, and can no longer be used as a "white space"; see below.) For example, consider the following decision table used as the "**Then**" clause of a conditional statement:

```
If Current-situation is Eur-demo-tac-nuc

   ["Eur-demo-tac-nuc" represents the situation in which one or both
    superpowers have used some tactical nuclear weapons in Europe,
    but have done so primarily for demonstrative purposes, i.e.,
    to coerce the opponent into terminating]

Then
{
  Table
  {
     Declare Basic-status# by example: Let Basic-status# be Basic-status.
     Declare Risks#        by example: Let Risks#        be Risks.
     Declare Escalation-guidance# by example: Let Escalation-guidance#
       be Escalation-guidance.

       If (Basic-status# is Basic-status or
            Basic-status# is Unspecified) and
          (Risks# is Risks or Risks# is Unspecified)
       Then
       {
            Let Escalation-guidance be Escalation-guidance#.
            Break.
       }
  }
```

Basic-status#	Risks#	Escalation-guidance#
goals-met	--	Eur-term
progress-good	low	Eur-demo-tac-nuc
progress-marginal	low	Eur-gen-tac-nuc
progress-good	marginal	Eur-demo-tac-nuc
progress-marginal	marginal	Eur-gen-tac-nuc .

```
}
```

Note the use of the **Break**. statement within the compound statement defining the operation of the **Table** statement, in order to stop the iteration through the table rows as soon as a satisfactory condition is found.

Much more succinct and powerful means of representing decision tables are being introduced into the next version of RAND-ABEL. Shapiro et al. (1985) contains a brief discussion of these ideas. Using these new table constructions, the table above reduces to the succinct:

Decision Table

Basic-status	Risks	/	Escalation-guidance
goals-met	--		Eur-term
progress-good	low		Eur-demo-tac-nuc
progress-marginal	low		Eur-gen-tac-nuc
progress-good	marginal		Eur-demo-tac-nuc
progress-marginal	marginal		Eur-gen-tac-nuc .

As a special case of the new table features, but one that greatly improves the readability and writability of RAND-ABEL programs, the above decision table has been made available in the currently operational version of the language.

The rules for constructing a *table-header* are as follows:

1. A *table-header* consists of one or more "text islands", each representing the name of a parameter (if a function is named) or the name of a local variable (if a *compound-statement* is used).
2. A "text island" is a two-dimensional grouping of characters such that each character of the group is directly adjacent (either horizontally or vertically, not diagonally) to some other character in the group.
3. In addition to hyphens (-) that occur as part of the identifier representing a parameter or variable name, dashes can be used as hyphens to continue the text within a text island onto the next line. These additional hyphens serve only as continuation characters, and are not considered part of the identifier itself. Note in the above example that the column heading:

```
amo-
unt
```

would match with the formal parameter "amount" in the definition of the function "Deploy". Note also that spaces are not permitted within an identifier used as a column header, so

indications of ownership in such an identifier (e.g., "Red's Presumed-opponent") are not permitted.

4. In addition to normal "white space" characters (space, tab, new line) and comments (enclosed in square brackets), the following characters are also considered "white space" in determining the "text islands" comprising a table header:

\ / _ =

5. If a "connector character" is useful in retaining the integrity of a "text island", the following characters may be used. They provide the adjacency required by Rule 2, but are not themselves considered part of the identifier represented by the text island:

| ( )

(These connector characters also "count" in determining the ordering of the text islands; that is, their position as part of a column heading helps determine the relative position of that column heading.)

6. At times it is desirable to abbreviate a formal parameter's name, or split it between two or more lines. An apostrophe (') may be used as a "wild card" character to match zero or more characters in the parameter name. Also, additional hyphens may be used to make a name split between lines more readable, as described in Rule 3. For example, a formal parameter entitled "Responsible-Party-Action" might be represented by either of the following two "text islands" within a table header:

Resp'ble- Party-Action	Respon- sible- Party- Action

7. If a table header is void--that is, after all special comment characters (including the characters listed in Rule 4) are removed from a table header, there are no remaining valid text islands in the header--and if the table contains a compound statement rather than a function name as part of its specification, the formal parameters will be ordered according to their order of appearance in the initial declarations within the compound statement. A table heading for a table statement that calls a named function may not be void.

The following example is a table header contrived to demonstrate most of the above rules:

Table Red-to-3rd-countries

country- (affected	side	cooper- ation	/=european-=====swa-====\ /=involvement==involvement=\	
France	Blue	Noncoordinate	Noncombatant	Noncombatant
GDR	Red	Coordinate	On-Call	Noncombatant .

This example calls the function "Red-to-3rd-countries" twice (once for each row of the table). The data in the table body are matched to five function parameters having the following names: country-affected, side, cooperation, european-involvement, and swa-involvement. Those function parameters need not have been declared or defined in that order.

The use of the vertical bar (|) as a connector character keeping a "text island" together within a *table-header* allows text headings to be associated with individual columns of a table in a very flexible way. Consider the following valid RAND-ABEL table statement:

Table Initialize

Region	Country-set [is it a country?, not a region/sea]	Superpower-set [is it one?]	Player-status [should the model simulate it?]	Borders-WP	Assertive-country [always fight on attack]	Nuclear-capable	Leader	Member ship	Orienta tion	Temperament	Red-presence	Blue-presence	Decision-delay [1-366] [days]
Afghanistan	Y	N	Y	Y	N	N	USSR	--	Red	Captive	Major	None	1
Arabian-Sea	N	N	N	N	N	N	--	--	--	--	--	--	--
Australia	Y	N	Y	N	N	N	UK	ANZS	Blue	Moderate	None	Token	2
Austria	Y	N	Y	Y	N	N	--	--	White	Reluctant	None	None	4
Belgium	Y	N	Y	N	N	N	US	NATO	Blue	Reliable	None	TripW	1

At times, more table columns are needed to describe a situation than will fit in the width of a single page. To allow wide tables to be described, the following additional format rules for a *table-header* allow a "wrap-around" header to be created, in which one or more additional rows of "text islands" provide the needed continuation.

Rules for constructing a multi-row *table-header*:

1. Table headers may be continued onto succeeding lines, if all characters in text islands comprising one row of the header are below all characters comprising the previous row of the header.
2. Within a row of text islands, column headers are read left-to-right.

(Note that by this set of rules, the table above qualifies as having only a single row of column headers, since the vertical bars (|) associating text strings with columns keep the "text islands" defining each column header from being separated vertically.)

Multi-row table headers are best understood by example. Consider the following table statement, with six formal parameters:

Table Function-of-6

First-parameter	Second-parameter	Third-parameter	Fourth-parameter
	Fifth-parameter	Sixth-parameter	
12.5	Green	512	"String 1"
	10002	(A + 10)	
9.0	Blue	221	"String 2"
	9943	(A - 24)	

Note that a blank line has been used to clearly separate the first and second rows of the table header; this is not strictly necessary, but aids in keeping the text islands separate. Note also that the entries in the table body "wrap around" in the same manner. In fact, the entries are merely read a line at a time, and matched to the corresponding headers in the table header. Although they have been staggered so that they may be placed beneath their corresponding header, this is again not strictly necessary; it simply aids comprehension of the table.

The rules for a *table-body* are simple: A *table-body* consists of a sequence of entries, each of which is a *unitparam*. (See Section IV for the formal definition of a *unitparam*. It is essentially a primitive value or a parenthesized expression.) The following additional rules hold for a *table-body*:

Rules:

1. If the *table-header* describes n formal parameters or variable names, then the number of entries in the table body must be a multiple of n. (Normally, the entries are placed in columns beneath the column headers within the *table-header*, so that each row of the table naturally consists of n entries, except when wide rows spill over onto the next line as in the example above.)

2. Each entry must match in type with the corresponding formal parameter or local variable.

The *table-header* and *table-body* are each followed by a period (.) as delimiter.

The RAND-ABEL Translator that interprets a table merely counts n entries in the table body, either calls the named function or executes the *compound-statement*, then acquires the next n entries (until a "." is encountered instead). There is no meaning attached to the grouping of table entries into rows.

FUNCTIONS: INVOKING AND EXITING

The declaration of functions was covered in Section V, and Section VI discussed the definition of functions and the syntax for a *function-invocation*. Functions returning a value are invoked by the expression **Report from** *function-invocation*. Functions not returning a value (presumably executed for their side effects) are invoked by a **Perform** statement, discussed here as part of a description of all RAND-ABEL statements. We also present here the **Exit** statement that allows completion of a function's execution, whether or not it returns a value.

statement

Perform *function-invocation*.

Rule: This statement is used to execute a function which does not return a value. (That is, it is executed for the side effects it causes.)

In some programming languages, a function not returning a value is called a subroutine. In RAND-ABEL, all program logic is contained in functions; a function not returning a value is equivalent to a subroutine.

Example: **Perform** force-ratio-calc
using France **as** side-1,
Yugoslavia **as** side-2,
and 3.5 E 4 **as** multiplier.

Within the statements defining a function, the following statement is used to return program control to the place from which the function was invoked:

statement

Exit.
Exit Reporting *simple-expr.*

Rules:

1. If the **Reporting** clause is omitted, the function does not return a value.
2. If the **Reporting** clause is used, the function always returns a value of the same data type as the *simple-expr*.
3. If there is more than one **Exit Reporting** statement within the definition of a function, then each of those statements must contain an *expression* of the same data type. However, the *simple-expr* may be of an ambiguous data type if that ambiguity is resolved by the function's declaration.

If a function does not return a value, it is always invoked by the RAND-ABEL statement:

Perform *function-invocation.*

If a function returns a value, then it is always invoked using the expression:

Report from *function-invocation*

Even functions reporting a value may have side effects, and in that sense are not equivalent to a mathematical function.

Examples:

```
Exit.
Exit Reporting "Success."
Exit Reporting ((multiplier * force-ratio)/2.0).
```

INPUT/OUTPUT

Explain, Record, Print, Log Statements

The following I/O statements are used to communicate with the "outside world"--the computer system environment within which RAND-ABEL is running.

Before the formal syntax description, some general terms should be understood by the reader. RAND-ABEL operates within a C language environment, within the UNIX operating system. The general characteristics of C and UNIX are assumed. The UNIX system has the (very powerful) concepts of "standard input" (which is often a terminal's keyboard) and "standard output" (which is often a terminal's display screen). Input and output consist of a stream of characters, which are usually directed to the standard input and output ports. However, these data streams can be redirected, for instance into a file, or into the output or input streams of another process running in the computer.

As data are emitted from a RAND-ABEL program, it is either formatted (according to its data type) in a standard (i.e., default) manner, or the programmer can exercise some control over the format in which it appears. A special language of format codes, consisting of a string of characters, is used to specify formatting of I/O. The default formatting for each of RAND-ABEL's data types, and the special format codes, are described in this section.

statement

Explain *unitparam . . . unitparam.*
Explain with *format-spec unitparam . . . unitparam.*

Record *unitparam . . . unitparam.*
Record with *format-spec unitparam . . . unitparam.*

Print *unitparam . . . unitparam.*
Print with *format-spec unitparam . . . unitparam.*

Print *streamname unitparam . . . unitparam.*
Print *streamname* **with** *format-spec unitparam . . .*

. . . nitparam.

Log *unitparam . . . unitparam.*
Log with *format-spec unitparam . . . unitparam.*

Log *streamname unitparam . . . unitparam.*
Log *streamname* **with** *format-spec unitparam . . .*

. . . unitparam.

Rules:

1. The **Explain** statement and the **Log** statement work together. The **Explain** statement appends a stream of data (defined by the sequence of *unitparams* within the statement) to a special "explain string". It DOES NOT actually perform any output to the log file. **Explain** only alters the explain string, in preparation for the possibility that a **Log** statement may be executed sometime later in the program.
2. The **Log** statement causes the current "explain string" to be sent to the output stream, appending any *unitparams* included in the **Log** statement. It has no effect on the explain string, which is "pushed" and "popped" with the stack maintained by an executing C language program; the result is that the explain string has the same scope as a local variable in the program. All entries in the "explain string" caused by **Explain** statements are lost if a RAND-ABEL program does not issue a subsequent **Log** statement.

3. The **Print** statement causes a stream of data (defined by the sequence of *unitparam*s within the statement) to be sent to an output stream.
4. The default output stream is the UNIX *stdout*; if a *streamname* is given, output from **Print** or **Log** is directed to that output stream instead.[1]
5. The **Record** statement has the same effect as the **Print** statement, except that the output stream is a specially designated "record" file.
6. If the optional **with** *format-spec* clause is omitted, all output is formatted according to standard defaults determined by the data types of the *unitparam*s being output.
7. If the **with** *format-spec* clause is included, the *format-spec* is a RAND-ABEL expression of type string. The character string is interpreted as a specification for formatting output, and output is formatted according to its specifications.
8. A value of type pointer can be output as a hexadecimal number for debugging purposes, but this is not expected to be used in a production program.

Unitparam is defined in Section IV. Basically, it is a simple value or a parenthesized RAND-ABEL expression.

Default output formats are used for each data type when no control is provided by an explicit *format-spec*. These default output formats are described in the following subsection.

Examples of the **Explain**, **Record**, **Print**, and **Log** statements are given at the end of this subsection, after the various formatting options are presented.

---

[1]If the RAND-ABEL program is executing in the context of the RSAC system, output should not be sent to the default *stdout*, as this will conflict with system CRT screen management.

Default Output Formats

If no special format controls are given, each data type has a standard way in which its value is printed. These default output formats are given by the following table.

Data Type	Default Output Format
Integer	A string of digits, with an optional prefix minus sign. No decimal point. Delimited by one blank on each side.
Real	A string of digits with an embedded decimal point. At least one digit is printed before and after the decimal point, even if it is a zero. Optional prefix minus sign. Numbers less than one-millionth (1 E -6) are considered zero. Otherwise, for numbers less than one, enough decimal places are printed to show at least two digits of significance. Delimited by one blank on each side.
String	The string is printed literally, with no surrounding quotation marks, and not delimited by blanks.
Boolean	The string "Yes" or "No" is printed, without surrounding quotation marks. Delimited by one blank on each side.
Pointer	A pointer-type value is output as a hexadecimal number for debugging purposes, using the same conventions as an Integer.
Enumerated	The identifier constant is printed without surrounding quotation marks. Delimited by one blank on each side.

Format Specification

A *format-spec* is used to control the formatting of output. It is a sequence of characters that are printed as listed, except when the special characters "%" and "\" are encountered. The % is followed by a special formatting code. The formatting codes recognized by RAND-ABEL are as follows:

%i	Enumerated data type
%s	String
%b	Boolean (**Yes** or **No**)
%d	Integer without a decimal point
%e	Real (or floating point) scientific notation
%f	Real (or floating point) fixed decimal point
%g	Real (or floating point) general; uses scientific notation or fixed decimal point, whichever is shortest.

A literal percent sign is entered in a format string as %%.

A number may be placed between the percent sign and the letter. That number specifies the overall number of characters allocated to the value. If a number is used, the field will be blank padded, unless the field width number begins with a leading zero, in which case the field will be zero padded. The field width number can optionally be followed by a decimal point, and then another number. The second number will be the number of digits to appear after the decimal point for %e, %f, or %g formats.

There are other special options that can be used in these format strings. They obey the conventions of "printf(3)" in Section 3 of the *UNIX Programmer's Manual*, Bell Laboratories. That document should be consulted for more detailed information.

The backslash (\) is followed by a character or sequence of three octal digits that represent special characters:

\n	Newline (line feed)
\r	Carriage return
\t	Horizontal tab
\b	Backspace
\f	Formfeed
\\	Backslash
\'	Single quote
\ddd	Any bit pattern (exactly three digits in octal notation)

These special escape sequences allow any ASCII character to be produced. For example, "\n" allows more than one line of text to be put in the same string, and "\f" causes a page eject. By using a three-digit octal (i.e. base 8 number system) code, any ASCII character can be

produced; e.g., one could make the CRT terminal "bell" ring by the following statement:

Print "\007".

Streams

A stream is a pathway through which information is transferred from a program to a terminal, file, or other program. The information is transferred as a stream of characters.

The normal output stream for **Log** and **Print** statements is the UNIX "standard output", which is initially set to the user's terminal.

If a *streamname* has been used in a **Log** or **Print** statement, but that stream has not yet been opened, then a run-time error will be generated.

The three pre-declared and pre-opened streams are: "Input", "Output", and "Error".[2] "Input" is the stream of characters received from the user's terminal keyboard. Reading a character from Input causes UNIX to wait for the user to type in a line of input text. "Output" corresponds to the user's terminal screen. **Print**ing a line on the stream "Output" causes the line to appear on the user's terminal. "Error" is also directed to the user's terminal. It is defined separately from "Output" since the program may want to redefine one of these to go somewhere else.

RAND-ABEL supports three pre-defined stream-oriented functions. They are:

Function Name	Argument 1	Argument 2	Return Value
Open-stream	*file-name*	*mode*	*streamname*
Close-stream	*streamname*		(none)
Flush-stream	*streamname*		(none)

[2] It will help the C programmer to know that these correspond directly to C's *stdin*, *stdout*, and *stderr*.

In the above function calls, *file-name* is a string argument that is either a UNIX file name or a full UNIX pathname (i.e., giving directory, subdirectory, etc.). *Mode* is one of the strings: "read", "write", "append". The value returned from the Open-stream function should be assigned to a integer variable which stores the ID of the stream. This same variable is then used as an argument to the Close-stream and Flush-stream functions.

The Open-stream function associates a UNIX file or path, in read, write, or append mode, with a *streamname*. If a file is opened in write mode and the file does not exist, it is created. If the file does exist, it is deleted first. If a file is opened in append mode, all writing to that file is appended to the end of the existing file, if any.

The Close-stream function closes a stream, making it unavailable for further use (until reopened). It is standard practice to close streams when they will no longer be used by the program.

The Flush-stream function is useful primarily for debugging. Typically, when a RAND-ABEL program executes a **Log** or **Print** statement, the only effect is to fill that file's buffer in the operating system. Later, the operating system will write the file to disk. This buffering of output provides significant performance advantages. The buffer will be written to the appropriate file when a RAND-ABEL program stops execution in the normal manner. However, it is possible for a RAND-ABEL program that has an error to abnormally exit without first writing the buffer to disk. This can cause the programmer to think that his RAND-ABEL program terminated at a point much earlier than is actually the case. To get around this problem, the Flush-stream function can be called to write the contents of the buffer to disk. Because continued use of this function can degrade system performance, it is used primarily for debugging purposes.

Since "Input", "Output", and "Error" are already pre-declared by the system, they can be used to declare other stream variables. For example:

Declare Output-file **by example**: **Let** Output-file **be** Output.

Examples of Input/Output Statements and Functions

The following examples illustrate many of the possible uses of the various input/output statements and functions described in this section:

```
[ Declare Message-file to be a streamname ]

   Declare Message-file by example:  Let Message-file be Output.

[ Use the Open-stream function to associate a UNIX file with this
  streamname, and set its mode to write-only ]

   Let Message-file be Report from Open-stream
        using "~anderson/ABEL/programs/messages" for file-name
          and "write" for mode.

[ Perform a set of writes to that file ]

   Print Message-file with "Threat level is now: %5d in country: %i\n"
                               threat (Report from select-country
                                         using Country-list as options).
   Print Message-file with "Force ratio is %3.1f at time %d \n"
                               ratio game-time.
   Print Message-file "End of game reached. \n\n"

[ Record program status; note that since a special file is
  written by the record statement, no file need be opened for
  this purpose ]

   Record "Program reached stage 3.\n"

[ Close file ]

   Perform Close-stream using Message-file.
```

COMPOUND AND NULL STATEMENTS

A compound statement is a sequence of zero or more declarations followed by a sequence of zero or more RAND-ABEL statements, all delimited by braces. It can occur wherever a *statement* can. It allows more complex program logic to be described than is allowed by the basic set of RAND-ABEL statements:

statement

{ *declaration* . . . *declaration*

statement . . . *statement* }

Rules:

1. All *declaration*s occurring within a compound statement are local to that statement; they have no effect outside that statement.
2. Each *declaration* is processed in turn, then each *statement* is executed in turn. To obtain more control flow options, conditional and repetitive execution statements can be used, as well as function invocations.

Notice that a *function-definition* is not allowed within a compound statement. All function definitions are at the "top level" of a RAND-ABEL program.

The compound statement is not terminated by a period, since a period occurs as a delimiter to the last statement within its body. If the compound statement requires more than one line of program text, it is traditional to line up the braces vertically, for ease in visualizing the matches between balancing braces. This positioning is for human consumption only; it is not used by the RAND-ABEL Translator.

Example: The following set of nested conditional statements uses compound statements to denote the set of RAND-ABEL statements to be executed at various places within the conditional logic. This example was given earlier in this manual.

```
If user-response = "Y" or user-response = "YES"
Then
{ Perform Recalculation.
  Print   "Calculation Completed.  More? (Y/N): "
  Let user-response be Report from query-user.
}
Else If user-response = "N" or user-response = "NO"
     Then
     { Print "No action taken.  More? (Y/N): "
       Let user-response be Report from query-user.
     }
     Else If user-response = "?"
          Then Perform Help-function.
          Else
          { Print "Your response not understood."
            Perform Help-function.
          }
```

A null statement consists of a period, the normal terminating delimiter on a RAND-ABEL statement, only. It is useful within conditional statements to control logic flow.

statement

```
.
```

Rule: This statement has no effect.

Note that a side benefit of this statement is that extraneous periods used in error as statement delimiters (for example after a conditional statement) do not cause a syntax error and have no effect.

Example: The following example, used earlier in this manual, illustrates the use of the null statement to control logic flow within a conditional statement.

```
If king-unchecked Then.  Else Perform Think.
```

VIII. META-STATEMENTS

The following special statements can be used to influence how RAND-ABEL programs are written and interpreted.

#DEFINE

The **#Define** statement provides an ability to create a macro giving a synonym or alias for a string of characters to be substituted wherever that macro identifier appears:

meta-statement

#Define *name* [*unquoted-string*].

Rules:

1. The *name* may be any RAND-ABEL *identifier*.
2. Wherever that identifier appears, it is replaced by the *unquoted-string* sequence of characters BEFORE the RAND-ABEL Translator interprets the resulting statement.
3. After replacement, the RAND-ABEL Translator continues its scan at the beginning of the replacement string, so any **#Define** identifiers it contains will similarly be replaced. **#Define** statements may be nested to any level.

This form of "macro string substitution" can be used to change the surface appearance of RAND-ABEL programs. It should be used cautiously, since the resulting programs might well become less readable to persons who know the RAND-ABEL language.

Example:

```
#Define c-decl
   [ Declare country by example:
        Let country be {France, Germany, Spain}.
   ].
```

INCLUDE

meta-statement

Include "*filename*".

Rules:

1. The contents of the file whose name (or pathname) is given are inserted at this point in the RAND-ABEL (or C) program. The file name or pathname is interpreted relative to the UNIX directory containing the current source file.
2. After the text insertion takes place, interpretation of the resulting file begins at the start of the newly inserted text lines, so if they contain **Include** statements, those statements are executed as they are encountered. **Include** files can be nested up to eight levels deep.

An **Include** statement is often used to incorporate a standard set of declarations or definitions into a RAND-ABEL program.

Example: **Include** "libraries/red-agent/dictionary.D".

MEMORIZE AND RECALL

meta-statement

Memorize *name* [*unquoted-string*].

Recall *name*.

Rules:

1. The **Memorize** statement associates a string of text with the given name (any identifier).
2. That text can then be inserted anywhere in the RAND-ABEL program by using the **Recall** statement.

This pair of statements is useful in "bundling" a set of Data Dictionary declarations under a name, then merely invoking that name wherever they are needed.

Memorize allows a number of program lines to be recalled by a single identifier, and requires the **Recall** keyword to be used along with the identifier to recall them. By contrast, **#Define** text cannot include multiple lines, and the identifier itself is sufficient to recall the text. **Memorize ... Recall** is less efficient than **#Define** because it creates a temporary file to store the memorized text.

Example:

```
Memorize my-data
   [ Read: Blue.
     No Read: Red.
     Initialize.
   ].

Recall my-data.
```

The **Recall** statement in the example above would be replaced in the RAND-ABEL program by the following Data Dictionary declarations:

```
Read: Blue.
No Read: Red.
Initialize.
```

DEBUGGING: TRACE AND UNTRACE

statement

Trace If.
Function.

Untrace If.
Function.

Rules:

1. **Trace** turns on reporting for either **If** statements or function invocations; **Untrace** turns off reporting.
2. All trace data are appended to a special file named "debug.out" within the current UNIX directory.

Function trace data consist of readable statements upon entrance to a function stating the function's name and the values assigned to each of its formal parameters. If the function returns a value, that value is reported to the file upon exit from the function.

"If" trace data write to the same "debug.out" file. Each execution of a conditional statement, when **Trace If** is on, causes the conditional statement itself to be written to the file, along with an indication of whether the *Boolean-expression* evaluated to **Yes** or **No**.

Trace and **Untrace** are not executable statements. Rather, they are commands to the RAND-ABEL Translator to embed tracing information within the generated C program. **Trace** and **Untrace** statements can be nested; an **Untrace** turns off the corresponding nearest **Trace** of the same type.

Tracing can significantly reduce the speed of RAND-ABEL program execution, and tends to generate large amounts of output. It should therefore be used selectively and only during program development.

ESCAPE TO C

statement

C Statement @ *C-code* @.

Rules:

1. The *C-code* is a sequence of valid C language statements, which is executed according to the normal rules for that language.
2. Anywhere within the *C-code* that a *C-expression* can occur, it can be replaced by a RAND-ABEL *expression* delimited by a back quote mark (`).

The escape back into RAND-ABEL from within *C-code* is particularly useful in writing valid RAND-ABEL identifiers within the C code, and to permit access to RAND-ABEL data from within the C code.

Although not part of the RAND-ABEL *statement* syntax, one can also escape to C code wherever a valid RAND-ABEL *expression* occurs; the RAND-ABEL *expression* can be replaced by a C language expression enclosed in at-sign (@) marks.

Example:

```
Declare Cosine by example:  Let 1.0 be Report from
        Cosine using real-in as x.
Define  Cosine:
        C Statement
        @
           #include <math.h>
           return (double) cos( (double) `x` ) ;
        @ .
End.
```

The above example declares and defines a new RAND-ABEL function that returns the cosine of its argument, called x. It uses the C language math library function "cos". "Cos" takes a C language double-rpecision floating point argument, and returns a double-precision floating point result. Thus coercion of both input and output of the

C cos function is advisable. The RAND-ABEL variable x is referenced within the C code by means of the "escape back to RAND-ABEL" provided by the back quotes (`). This function would be called from RAND-ABEL as follows:

```
Declare cos-answer by example: Let cos-answer be 1.0 .
Let cos-answer be Report from cosine using 3.14159 as x.
```

IX. DATA DICTIONARY

The Data Dictionary facility in RAND-ABEL permits large, complex systems to be developed from separate modules that are created individually by different teams of analysts. It is a much more elaborate and useful facility than the old concept of a "common" area in programs that stores data used in common by the different programs.

The RAND-ABEL Data Dictionary describes the contents and attributes of a data set to be used in common by all the RAND-ABEL modules comprising a system.[1] This common data set contains the specification of:

- A list of items (variables, attributes, tables) to be included in the common data set.
- A list of items, similar to the list above but including sub-procedures and functions, which are not part of the common data set.
- A structuring of the source files which make up the system.
- Access restrictions, ownership, method of implementation, and other such attributes for data items and source code.
- Ancillary information such as the author, module name, and other administrative attributes associated with data items and source code.

The Data Dictionary consists of a set of files that are maintained in an extended RAND-ABEL language. The RAND-ABEL processor translates these files into C language data structures. The resulting C code can be used by a system monitor (a special program providing the foundation for the system being developed) for allocating memory for the data items described, and also by a front-end data editor that can display and manipulate these items.

---

[1] In the Rand Strategy Assessment Center, this common data set is called the World Situation Data Set (WSDS).

A Data Dictionary entry begins with a **Declare** statement (see Section V). After the declaration of an item follow a number of statements describing the item. The sequence of descriptions is ended when a new **Declare** is found for the next item, a new **Default** statement is reached, or the **End Declarations** statement is encountered.

Many attributes associated with a data item will be the same for an entire group of items (e.g., author, access restrictions, etc.). To avoid the need for typing a whole list of attributes for each item, default attributes may be declared. When a default is declared, it affects all subsequently declared data items within the current file and any files "Included" within that file. A default does NOT affect any files which have "Included" the file which contains it. This nested-default mechanism allows higher-level files to create default environments for lower-level files without worry of a default in a lower-level file causing side effects.

The set of Data Dictionary declarations has the following syntax:

data dictionary specification block

Begin Declarations.

declaration

DDdeclaration . . .

DDdeclaration

declaration

DDdeclaration . . .

DDdeclaration

. . .

End Declarations.

The individual data dictionary declarations (i.e., *DDdeclaration*s) are of three types:

1. *Defining declarations*. Information that actually affects the object code, such as type, size, or access data.
2. *Identifying declarations*. Information that is documentary but mandatory.
3. *Informative declarations*. Information that is optional but useful as documentation.

Each of these categories of declarations is described below.

DEFINING DECLARATIONS

These declarations are mandatory for each external data item, but may be handled by default declarations that are in effect (see p. 81).

DDdeclaration

Method: **Direct**.
Function.
Macro.

Function: *func-name*.

Macro: *string-literal*.

Rule: **Method** means "method of access". An item's access method tells whether the variable is accessed directly or via a function or macro. If an item is accessed via a macro, the macro must be defined using a **Macro** statement. If it is accessed via a function, the name of the function must be given using the **Function** statement. The **Macro** or **Function** statement must immediately follow the **Method** declaration.

Examples:
```
Method Function.
Function: calculate-attrition.

Method Macro.
Macro: gov2cntry(F,i)
   ((*GOVERN_entry)(char *)F + i) - F->governs + 1.
```

DDdeclaration

Use: Clone.
No Clone.
Constant.

Rule: The **Use** declaration indicates whether an item is to be created dynamically (**Clone**) when the Push function is invoked and discarded when the corresponding Pop function is executed; or whether one instance of the data item is to be maintained throughout a Push and Pop (**No Clone**). Data that are never changed during program execution are declared with the **Constant** option.

Example: **Use: No Clone.**

DDdeclaration

Owner: *owner-name*.

Global.

Rule: This declaration allows different modules to have separate items with the same name. Source code also has an owner, and automatically accesses either its own or "global" data items, unless otherwise specified by this declaration. The "*owner-name*" is one of a set of commonly agreed-upon names by which the various groups developing code are identified. The keyword **Global** is used if there is no specific owner.

Examples: **Owner:** Red.
Global.

DDdeclaration

Read **Everyone.**
owner-name . . . *owner-name.*
owner-name , . . . , *owner-name.*

Noread **Everyone.**
owner-name . . . *owner-name.*
owner-name , . . . , *owner-name.*

Write **Everyone.**
owner-name . . . *owner-name.*
owner-name , . . . , *owner-name.*

Nowrite **Everyone.**
owner-name . . . *owner-name.*
owner-name , . . . , *owner-name.*

Rule: These declarations specify which source code owners (i.e. "access groups") can read and/or write this item. The "No" prefix can turn off a default or serve documentary purposes by establishing a lack of access for a particular group. The special group **Everyone** applies to all access groups, and can be used to grant or deny access for all groups.

Examples:
Noread Blue, Neutral.
Write Everyone.

DDdeclaration

Read Format: *string-literal.*

Write Format: *string-literal.*

Rule: The preferred format for reading and writing this data item is stated as a quoted string of format descriptors (see Section VII).[2]

[2]For programmers familiar with the C language: the format

It is desirable to specify output formats for string variables, integers, and real (floating point) data whenever possible, since it helps the display programs format the data in a consistent manner. It is unnecessary to specify output formats for enumerated variables since the field width needed to display them is easily determined by the display programs.

Example: **Write Format**: "%5.3f".

DDdeclaration

Validation Range: *numeral* **to** *numeral*.

Validation Function: *func-name*.

Rule: In the first form, an inclusive range of numeric values (either integer or real) is given. In the second form, a Boolean function is named that is expected to return **Yes** for a valid item, and **No** otherwise.

Examples: **Validation Range**: 2.7 TO 8.75.
Validation Function: Check-value.

DDdeclaration

Prompt Function: *func-name*.
String: *string-literal*.

Rule: In the first form, the named function will be called prior to input for this data item. It returns a string which will be displayed on the user's CRT screen. In the second form, a quoted character string is given for display prior to input of the data item.

---

specification is the same as those used for the *scanf* and *printf* functions.

If a RAND-ABEL simulation is being performed under the control of the system monitor, the monitor passes any string generated by the **Prompt** declaration to the user's terminal.

Examples: **Prompt Function**: Show-message.
Prompt String: "Type ratio as a decimal: ".

DDdeclaration

Initialize.

No Initialize.

Rule: This declaration indicates whether the item can be initialized by the RAND-ABEL Translator or not.

At this time, the **Initialize** declarations may be used in a program, but their effect has not been implemented. Consequently, they do not alter program behavior.

Examples:
Initialize.
No Initialize.

IDENTIFYING DECLARATIONS

These declarations are mandatory, but take an arbitrary comment as an argument. They are used for standardized documentation of a module.

DDdeclaration

Author: *comment*.

Date: *comment*.

Definition: *comment*.

Rule: The *comment* may be a free-format comment that aids in the documentation of the program or data item.

Examples:
```
Author: [ Mark LaCasse ].
Date:   [ 83/02/05 ].
Definition: [ This function returns a
              string value which should
              be displayed prior to input
              of the force structure ratio ].
```

INFORMATIVE DECLARATIONS

Informative declarations are optional. They provide additional structured documentation of a RAND-ABEL program module.

DDdeclaration

References: *comment*.

Comments: *comment*.

Status: *comment*.

Rule: The *comment* may be a free-format comment that aids in the documentation of the program or data item.

The **Status** declaration is often used to represent whether a variable is "proposed" (indicating the author is willing to entertain proposals for change), or "confirmed" (indicating the author has closed debate on the subject).

Examples:

References: [See R-1258, Section II].
Comments: [This function is a placeholder until
a more complete computation can be
developed].
Status: [Proposed].

CREATING AND REMOVING DEFAULT DECLARATIONS

As mentioned above, all the mandatory Data Dictionary declarations need not be given for each data item or function. Many of these declarations can be covered by use of declared defaults.

Any of the *DDdeclaration*s described in this section may be preceded by the keyword **Default**. If that is done, that setting for the particular *DDdeclaration* remains in force within the current file (and files **Include**d within it) until a new default is given or a **No Default** is declared for that type of *DDdeclaration*. Any default setting may be overridden by individual *DDdeclaration*s associated with a particular data item or function.

Examples:

Default Owner: Red-Agent.
Default Method: **direct**.
Default No Initialize.
Default Author: [Mark LaCasse, randvax!lacasse].

The following **No Default** statements may be issued to remove a default setting on a type of *DDdeclaration*:

DDdeclaration

```
No Default Author.
           Comments.
           Date.
           Definition.
           Initialize.
           Method.
           Owner.
           Prompt Function.
                  String.
           Read Format.
           Write Format.
           References.
           Status.
           Use.
           Validation Function.
                      Range.
```

When **No Default** is specified for any mandatory *DDdeclarations*, such a *DDdeclaration* must accompany each data item or function until the next **Default** or **End Declarations** statement is reached.

Examples of **No Default** statements:

```
No Default Comments.
No Default Prompt String.
No Default Read Format.
No Default Validation Function.
```

EXAMPLE OF A DATA DICTIONARY DECLARATION SECTION

The following is a complete example of a Data Dictionary declaration section within a RAND-ABEL program. Such a RAND-ABEL code section is often contained in a file that can be **Included** within another RAND-ABEL file to obtain the standard defaults and definitions required.

```
[ Sample Data Dictionary Entries for Blue Agent, January 1984 ]

Begin declarations.

   Default Owner:          Blue.
   Default Method:         Direct.
   Default Read:           Blue.
   Default Write:          Blue.
   Default Use:            Clone.
   Default No Initialize.
   Default Author:         [ Mark LaCasse, randvax!lacasse ].
   Default Date:           [ 84/01/05 ].

   Declare Lookahead-opponent by example:
       Let Lookahead-opponent be
         {
           BR1,     [ Blue's Red version one ]
           BR2      [ Blue's Red version two ]
         }.
         Definition: [ Blue's Red, opposes Blue in Lookaheads ].

   Declare Time-to-wake by example:
       Let Time-to-wake be 45786.
         Prompt String:
          "Enter the date and time in the format: MMM DD, hh.mm".
         Validation Function: Check-time-input.
         Definition: [ General purpose, future time to wake Blue ].

End Declarations.
```

X. CO-PROCESSES

A co-process is a process (that is, an executing program) that is started by another process, which then executes independently and asynchronously of its parent process. This section discusses how co-processes are created, put to sleep, and terminated.

CREATING A CO-PROCESS

Co-processes are created by calling a built-in RAND-ABEL function called "Start-co-process". It takes two arguments, *proc-start* and *proc-name*. *Proc-start* is given an object representing the top-level function of the to-be-created process. This object can be created by use of the **function** expression. *Proc-name* is a string identifying the new process. The function Start-co-process returns an object which is of type process. Therefore, the initiation of a new process might be performed by a statement such as the following:

```
Declare new-proc by example: Let new-proc be Self.

Let new-proc be Report from Start-co-process
                using (Function Top-of-proc) as proc-start
                  and "Offensive strategy" as proc-name.
```

Note the use of the expression (**Function** Top-of-proc) to create an object representing the user's function named "Top-of-proc", which is to be executed as the beginning of the new process.

The execution of the Start-co-process function is the only method by which a value of type process can be created.

PUTTING A PROCESS TO SLEEP

A process can cause itself to "go to sleep"--that is, to stop processing until it is awakened by some external program. This is done by activating a built-in function called "Sleep". Sleep takes no arguments and returns no value:

```
Perform Sleep.
```

There are no facilities within the RAND-ABEL language itself for awakening a function once it is sleeping; at present, those facilities are part of the support environment in which a RAND-ABEL process resides, and must be invoked directly within that support environment. (See Appendix A for some further information on the support environment for RAND-ABEL.)

TERMINATING A CO-PROCESS

To terminate a co-process, the "Kill-co-process" function is used. It takes one argument, called process: an object of type process that identifies the process to be terminated. Therefore, to terminate the process created by the example above, one would write:

Perform Kill-co-process **using** new-proc **as** process.

RESERVED CO-PROCESS VARIABLES: SELF AND PARENT

The RAND-ABEL system contains two reserved process-type variables: **Self** and **Parent**. **Self** is always equal to the current process. **Parent** always refers to the parent process that spawned a given process. These variables can also be used in **Declare** statements as examples of processes, so that new variables of type process can be declared.

RULES FOR THE USE OF CO-PROCESSES

The following rules govern the use of co-processes.

1. A co-process may not call Kill-co-process on itself.
2. Processes can be the object of assignment statements, so that statements such as:

   Let me **be Self.**

   are valid.
3. Processes can be values of suitably defined variables or arrays. This was illustrated in the above example, where "me" is a variable taking on a process as its value.

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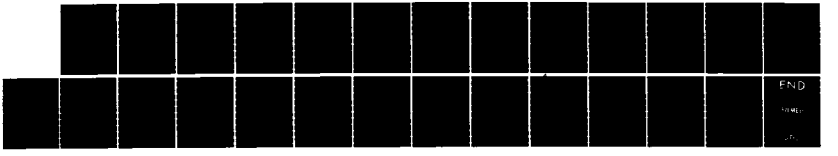
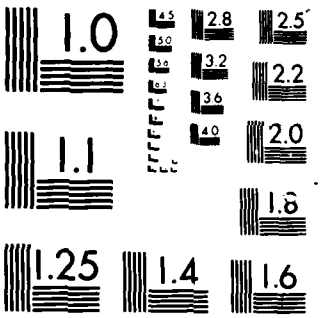




MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

4. Processes can be arguments of suitably declared arrays. For example:

```
Declare active_process by example:
    Let active_process be Self.

Declare array by example:
    Let array of active_process be 17.
```

5. Processes can be parameters of functions. For example, the built-in function "Kill-process" has as its single parameter an object of type process.
6. Processes are subject to no other operations.

XI. TOP-LEVEL RAND-ABEL DECLARATIONS, DEFINITIONS, AND STATEMENTS

The RAND-ABEL "language" is a complete programming language. However, only certain of the RAND-ABEL statements and declarations can occur at the top level of a RAND-ABEL program. All other RAND-ABEL constructions occur within these top-level statements and declarations.

The only RAND-ABEL declarations and statements that can occur at the top level are:

- Any valid RAND-ABEL **Declare**
- Any valid RAND-ABEL **Define**
- The RAND-ABEL *statements*:

  C Statement @ *C-code* @

  Trace If.
  Function.

  Untrace If.
  Function.

- One of the two mutually exclusive statements:

  Owner: *name*.
  Global.

- A special top-level-only **Declare**:

  Declare Ignore *name* . . . *name*.
  name , . . . , *name*.

- The set of declarations providing information to the Data Dictionary facility (see Section IX).

Begin Declarations.
declaration
DDdeclaration . . . DDdeclaration
declaration
DDdeclaration . . . DDdeclaration
. . .
End Declarations.

The meanings of all normal RAND-ABEL **Declare**s, **Define**s, and *statement*s are found in earlier sections of this Note. The meaning of the ownership statements (**Owner** and **Global**) is found in Section IX; when used here, the statements declare the ownership tag to be put on all subsequent RAND-ABEL code.

The **Declare Ignore** statement is used to add a set of *identifier*s to a list (initially null) that the RAND-ABEL Translator will ignore whenever they are encountered. These identifiers can then be used as "noise words" in RAND-ABEL statements, presumably to increase their readability.

For example, the declaration:

Declare ignore a, an, the.

allows one to write a RAND-ABEL statement such as:

Let the color **of** a piece **be** white.

which is equivalent to the RAND-ABEL statement using explicit comments:

Let [the] color **of** [a] piece **be** white.

or, the more brutally simple:

Let color **of** piece **be** white.

Care should be taken in the declaration and use of such noise words, since readers of RAND-ABEL code might overlook the **Declare Ignore** statement and believe that these words are part of valid

RAND-ABEL syntax, possibly leading them to write incorrect RAND-ABEL programs. Also, it should be noted that in normal English the phrases "a piece" and "the piece" mean quite different things, whereas they do not in a RAND-ABEL program in which both "a" and "the" are declared to be noise words, again creating the possibility of confusion in the RAND-ABEL reader's mind.

Appendix A
LOCAL SUPPORT ENVIRONMENT FOR RAND-ABEL

Appendix A briefly discusses the use of RAND-ABEL at The Rand Corporation. Its contents are specific to this site. Currently, RAND-ABEL is used at Rand only in the context of the Rand Strategy Assessment Center (RSAC). Consequently, the following guidelines are RSAC-specific.

The RAND-ABEL Translator is generally used in two modes: (1) as an aid in preparing syntactically correct RAND-ABEL rules, and (2) to produce compilable C code for actual incorporation into the executable RSAC model. The basic difference between (1) and (2) is the handling of the Data Dictionary.

Essentially, in preparing RAND-ABEL programs data items are frequently added, changed, or removed; as a result, the writer cannot use the master Data Dictionary, but his own extract of it. This seeming inconvenience can actually be an aid, as it forces the writer to be aware of how his program integrates with the other parts of the model.

In all cases, the writer incorporates the Data Dictionary into the program by the ABEL **include** statement (described in Section VIII). Since this mechanism allows nesting (that is, included files can contain other include statements), a two-level approach is used. At the top of a RAND-ABEL program file is an **include** for a single Data Dictionary file; this file in turn contains **include**s for all needed Data Dictionary components. In the finished program, the program file instead incorporates the master Data Dictionary file.

All Data Dictionary files end in ".D", whereas all RAND-ABEL program files end in ".A". The RAND-ABEL Translator is applied to the ".A" files only (with the **include**s introducing the Data Dictionary). The result of applying the RAND-ABEL Translator is (possibly) a series of error messages and two files: a ".A.c" file and a ".A.I" file. These files are then used to build the integrated RSAC model.

All Data Dictionary and RAND-ABEL program files are eventually registered with the RSAC Data Dictionary administrator for the final integration.

Running the RAND-ABEL Translator itself is quite simple. Applying it to the file "rules.A" would involve typing (on the randvax or text processor (TP) computers[1] used by RSAC):

```
/s/sl/rsac/bin/enabel rules.A
```

Most people will probably want to use an alias for this, and so will place the line:

```
alias enabel /s/sl/rsac/bin/enabel
```

into their ".cshrc" files.

In reviewing the error messages produced by the RAND-ABEL Translator, two things should be kept in mind:

- The range of legal RAND-ABEL language inputs is quite large; sometimes it takes several keywords for the RAND-ABEL Translator to detect that an error has occurred. Thus, not only should the line number and word printed by the RAND-ABEL Translator be checked for the error, but the code immediately preceding it as well.
- A problem with block-structured languages (like RAND-ABEL) in general, and with top-down parsers like the RAND-ABEL Translator in particular, is a difficulty in recovering from certain errors. (That is, there is often a problem in finding the start of legal statements after the error, and in recovering context skipped over because of the error.) As a result, it is quite possible for a single error to produce a hundred error messages. Thus, there are occasions where only

[1]The randvax and TP computers are both VAX 11/780s running 4.2BSD UNIX. The TP computer is authorized to handle material at the SECRET level.

the first error reported is an actual problem, while subsequent error messages are a result of declarations, definitions, or statement boundaries having been missed.

Note that this is not always the case. If a several-line gap appears between errors, there is a good chance that the later error is valid. However, an error in a declaration can cause spurious errors wherever the item being declared is subsequently used, even if thousands of error-free lines intervene.

In all cases, the RAND-ABEL program writer has to learn through experience and through sharing experience with other writers. Also, there are certainly cases where the RAND-ABEL Translator can do a better job of finding and reporting errors, and in recovering from them. Communication is thus very important.

Appendix B
QUICK-REFERENCE GUIDE TO THE RAND-ABEL LANGUAGE

The following is a list of RAND-ABEL keywords. Words that always occur in sequence as phrases are shown together; words are shown separately that are optional or are one of several possible choices within a phrase.

Address of
and
are not
as
Attribute
Author

Begin Declarations
Break
by

Clone
Comments
Concatenated with
Constant
Continue
C Statement

Date
Declare...by example
Decrease by
Default
Define
#Define
Definition
Describe
Divide...by
Divided by

End
End Declarations
Erasable
Erase
Evaluate
Everyone
Exit
Explain

For
Format
from
Function

Global

If...Then
If...Then...Else
Ignore
in
Include
Increase...by
Initialize
is
is at least
is at most
is greater than
is less than
is not

Let...be
Log

Macro
Make
Method
minus
modulo
Multiply...by

negative
No
Not

Occupant of
of
or
Owner

Parent
Perform
plus
Print
Prompt

Range
Read
Record
References
Report from
Reporting

Self
Semi-erasable
Status
String

Table
There is
times
Trace

Unerasable
Unspecified
Untrace
Use
using

Validation

While
with
Write

Yes

In addition, the following special symbols also act as keywords having special meaning:

@	--	(...)	{...}	[...]	,	:	.
+	-	*	/	%	~	$	
=	~=	>=	<=	>	<	&	|

In the above lists, ellipses (...) represent intervening words in a standard phrase. (Elsewhere in this manual, ellipses represent certain syntactic options.)

The following pages contain a summary of the RAND-ABEL syntax charts contained within this Note.

expression

Report from *function-invocation*

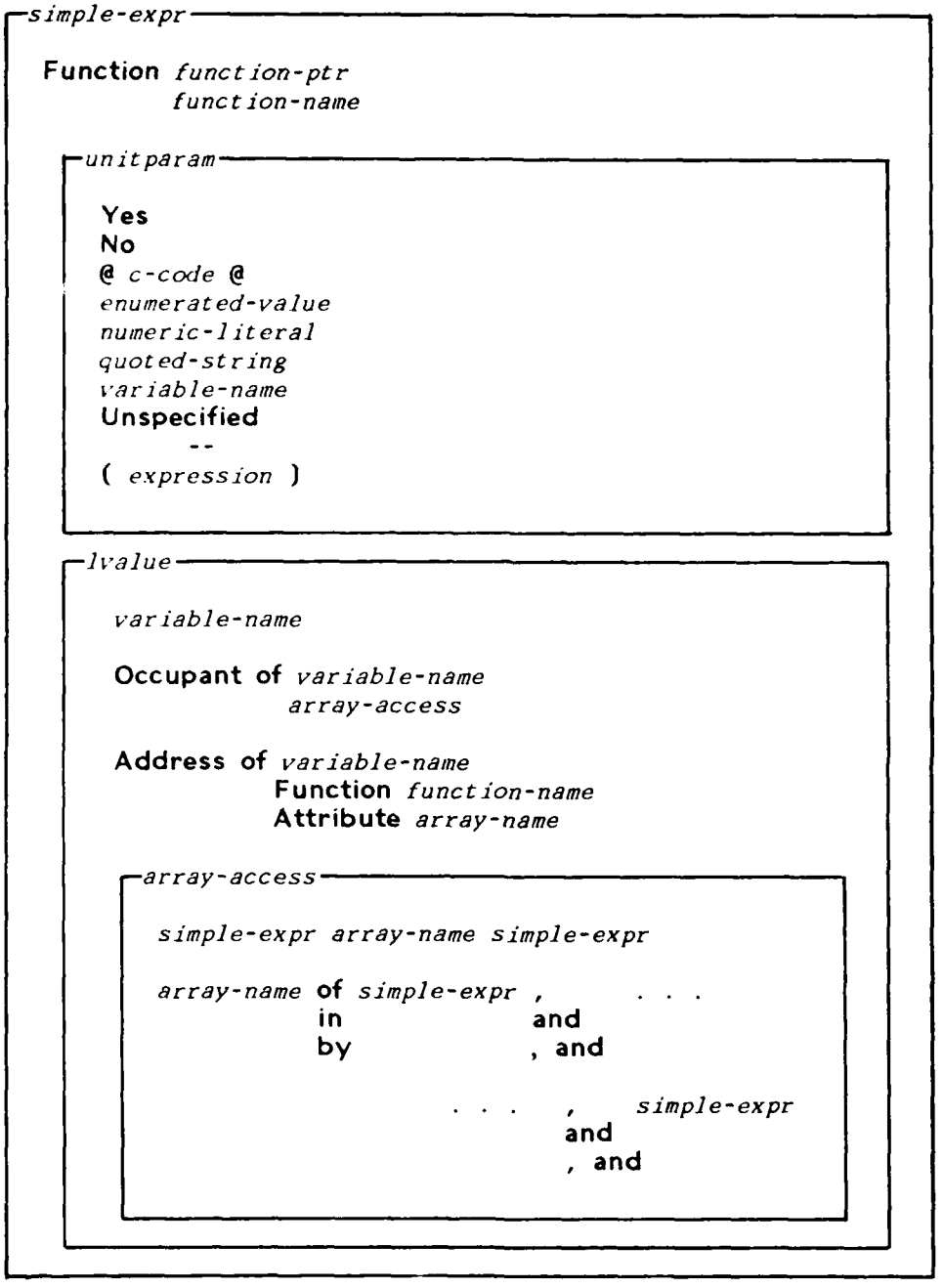
Evaluate *unitparam . . . unitparam*
with *format-spec unitparam . . . unitparam*

numeral variable-name
unary-operator expression
expression binary-operator expression

There is *array-access*
a *array-access*
an *array-access*

Describe *array-name*

simple-expr


simple-expr
Function function-ptr
function-name
unitparam
Yes
No
@ c-code @
enumerated-value
numeric-literal
quoted-string
variable-name
Unspecified
--
(expression)
lvalue
variable-name
Occupant of variable-name
array-access
Address of variable-name
Function function-name
Attribute array-name
array-access
simple-expr array-name simple-expr
array-name of simple-expr , . . .
in and
by , and
. . . , simple-expr
and
, and

declaration

Declare *variable-name* **by example:**

Let *variable-name* **be** *expression*.
{ *name* . . . *name* }.
{ *name* , . . . , *name* }.

Declare *array-name* **by example:**

Let *array-name* **of** *simple-expr* , . . .
in **and**
by , **and**

. . . , *simple-expr*
and
, **and**

be *expression*.
{ *name* . . . *name* }.
{ *name* , . . . , *name* }.

Declare *array-name* **by example:**

Let *simple-expr array-name simple-expr*

be *expression*.
{ *name* . . . *name* }.
{ *name* , . . . , *name* }.

Declare *func-name* **by example:**

Let *expression* **be Report from** *named-function-call*.
Perform *named-function-call*.

function-definition

```
Define func-name : declaration . . .
                   declaration
                     statement . . .
                     statement
End.
```

named-function-call

```
 func-name

 func-name  using expression as   param-name , . . .
                            for             and
                                            , and

                  . . . ,     expression as  param-name
                        and                 for
                        , and
```

function-invocation

```
 named-function-call

 func-ptr

 func-ptr   using expression as   param-name ,      . . .
                            for             and
                                            , and

                  . . . ,     expression as  param-name
                        and                 for
                        , and
```

statement

Let *lvalue* **be** *expression*.
pointer

Increase *lvalue* **by** *expression*.
Decrease
Multiply
Divide

If *Boolean-expression* **Then** *statement*

If *Boolean-expression* **Then** *statement* **Else** *statement*

For *variable* : *statement*

While *Boolean-expression* : *statement*

Continue.

Break.

Table *func-name*
compound-statement

table-header.

table-body.

Perform *function-invocation*.

Exit.
Exit Reporting *simple-expr*.

Explain *unitparam* . . . *unitparam*.
Explain with *format-spec unitparam* . . . *unitparam*.

Record *unitparam* . . . *unitparam*.
Record with *format-spec unitparam* . . . *unitparam*.

Print *unitparam* . . . *unitparam*.
Print with *format-spec unitparam* . . . *unitparam*.

Print *streamname unitparam* . . . *unitparam*.
Print *streamname* **with** *format-spec unitparam* . . .

. . . *nitparam*.

Log *unitparam* . . . *unitparam*.
Log with *format-spec unitparam* . . . *unitparam*.

Log *streamname unitparam . . . unitparam.*
Log *streamname* **with** *format-spec unitparam . . .*

. . . unitparam.

{ *declaration . . . declaration*

statement . . . statement }

.

Trace If.
Function.

Untrace If.
Function.

C Statement @ *C-code* @.

data dictionary specification block

Begin Declarations.

declaration

DDdeclaration . . .

DDdeclaration

declaration

DDdeclaration . . .

DDdeclaration

. . .

End Declarations.

DDdeclaration

Method: **Direct.**
Function.
Macro.

Function: *func-name.*

Macro: *string-literal.*

Use: **Clone.**
No Clone.
Constant.

Owner: *owner-name.*

Global.

Read **Everyone.**
owner-name . . . owner-name.
owner-name , . . . , owner-name.

Noread **Everyone.**
owner-name . . . owner-name.
owner-name , . . . , owner-name.

Write **Everyone.**
owner-name . . . owner-name.
owner-name , . . . , owner-name.

Nowrite Everyone.
owner-name . . . owner-name.
owner-name , . . . , owner-name.

Read Format: *string-literal.*

Write Format: *string-literal.*

Validation Range: *numeral* **to** *numeral.*

Validation Function: *func-name.*

Prompt Function: *func-name.*
String: *string-literal.*

Initialize.

No Initialize.

Author: *comment.*

Date: *comment.*

Definition: *comment.*

References: *comment.*

Comments: *comment.*

Status: *comment.*

No Default Author.
Comments.
Date.
Definition.
Initialize.
Method.
Owner.
Prompt Function.
String.
Read Format.
Write Format.
References.
Status.
Use.
Validation Function.
Range.

meta-statement

#Define *name* [*unquoted-string*].

Include "*filename*".

Memorize *name* [*unquoted-string*].

Recall *name*.

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