TYMSHARE REFERENCE MANUAL

NARP

AN ASSEMBLER FOR THE XDS 940

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Note

Certain sections of the following reference manual are written in a primer-like style, especially parts of the introduction and the discussion of macros. However, it is assumed that the reader is familiar with the logical operation of general-purpose digital computers, and, in particular, is acquainted with the SDS 940 instruction set (see the SDS publication, SDS 940 Computer Reference Manual, No. 90 06 40A, August, 1966.

The preface contains a discussion of the differences between NARP and ARPAS.

Acknowledgment

Much of this manual is similar to the ARPAS manual (ARPAS, Reference Manual for Time-Sharing Assembler for the SDS 930, Document R-26, February 24, 1967), written by Wayne Lichtenberger, and some paragraphs are taken verbatim from the ARPAS manual.

This manual was developed by the University of California at Berkeley under contract to Advanced Research Projects Agency and modified by Tymshare to reflect certain additions to the assembler.

0.0 Differences Between NARP and ARPAS

NARP (new ARPAS) has supplemented ARPAS as the assembler for assembly language programs written for Tymshare's XDS 940. The execution speed of NARP is considerably greater than that of ARPAS, and that is the main reason for the changeover. All users are encouraged to change their programs over to the NARP language as soon as practicable and new programs should surely be written in NARP. DDT and FOS will load programs assembled in either language or both.

NARP is by and large a superset of ARPAS, but there are some notable exceptions, the majority of which are described below.

The following list of differences between NARP and ARPAS is ordered after the ARPAS manual, with a few exceptions. To avoid ambiguities, a blank character is often denoted by a '␣'.

1) NARP is a one-pass assembler, not a two-pass assembler like ARPAS. Thus any sections of programs which depend on the fact that ARPAS is two passes will in all probability have to be carefully rewritten before NARP can handle it.

2) In addition to the opcodes listed in the ARPAS manual, Appendix A, NARP handles many additional opcodes. See NARP manual, Appendix A.

3) A symbol in NARP is a string of letters and digits that is not a number. A number is any one of the following:

   a) a string of digits
   b) a string of digits followed by the letter 'D'
   c) a string of digits followed by the letter 'B'
   d) a string of digits followed by the letter 'B' followed by a single digit. Thus, 14D2 and 14B10 are symbols, whereas 777B9 is a number.

4) The seven characters ! # % & @ \ ↑ <u>are</u> recognized by NARP. Thus they may be used freely, usually in strings, but not always, since some of them have meaning in NARP. Except for 135B (multiple blank) and 155B (carriage return), all characters with a value greater than 77B are ignored by NARP.

5) The classification of opcodes has been completely revised in NARP:

   class 0: the opcode may or may not have an operand (e.g., NOP)
   class 1: the opcode has no operand (e.g., CLA)
   class 2: the opcode has an operand (e.g., ADD)

   In addition to its class, a given operand is either a shift instruction or a non-shift instruction (note: this has nothing to do with whether the action of the instruction involves shifting, but is simply a way of distinguishing between two types of instructions). For a non-shift instruction, the operand is computed mod 2^{14} and merged into the instruction. For a shift instruction the following happens:

   a) if the indirect bit is set by '*' or '←' then the value of the opcode is trimmed so that b10-b23 are zero and the instruction is treated as if it were a non-shift instruction.

   b) if the indirect bit is not set as above then the operand is computed mod 2^9 and merged into the instruction; in this case, the operand must be defined and absolute. (note: With reference to NARP, the statement that a symbol is defined means it is defined at that instant and not at some later point in the program.)

   See the description of OPD (22 below) for more comments on opcodes.

6) A number may appear in the opcode field. In such a case, the value of this number is placed in b0-b8 of the instruction. The opcode has class 0 (i.e., operand optional).

7) NARP does not keep track of null symbols.

8) The tag field of an instruction must be defined (in the NARP sense, see 5b above) and absolute.

9) In ARPAS an expression may have a relocation factor of either 0 (absolute) or 1 (relocatable). In NARP, however, an expression may have any relocation factor, including a negative one.

10) The ARPAS notation (<letter string>) for operators does not exist in NARP:

ARPAS	NARP
(NOT)	@
(R)	does not exist, see 16 below
(LSS)	<
(GRT)	>
(EQU)	=
(AND)	&
(OR)	!
(EOR)	%

11) The precedence of operators is different in NARP than it is in ARPAS (see 17 below). In most cases this makes little difference and need only be worried about for things like (AND) (maybe not even in this case, since the description in the ARPAS manual may not correspond with reality).

12) A NARP expression may contain an expression enclosed in square brackets as a primary. For example, A EQU [N-3]*8 is legal.

13) A NARP expression may contain any number of relational operators.

14) String constants are <u>right-justified</u>. Thus 'A' = '␣␣␣A' = '␣␣A' = '␣A', 'A␣' = '␣␣A␣' = '␣A␣'. Also, a string constant may be at most four characters long; if it is longer, then an error message is typed and the first four characters of the string are taken as the value.

15) A NARP expression has the following BNF description:

<primary> :: = <symbol>|<constant>|[<expression>]
<basic expression> :: = <primary>|<primary> <binary operator> <basic expression>
<expression> :: = <basic expression>|<unary operator> <basic expression>.

The main point in the above syntax is that two operators may never be adjacent, so A & @B is illegal (write it as @B & A).

16) NARP is less finicky than ARPAS about relocation factors. Thus a relocatable quantity can be multiplied by an absolute quantity, yielding a relocation factor other than 0 or 1, e.g., (R)ALPHA when used to produce a string pointer becomes simply 3*ALPHA. The unary operator (R) does not exist in NARP (likewise, the directive RAD does not exist in NARP). The following table shows the permissible relocation factors for the operands of the various operators, as well as the relocation factor of the result (see 17 below for descriptions of all the operators).

NOTE: In the following table, R1 is a symbol with relocation factor of 1 and R2 is a symbol with relocation factor of 2. Relocation factor is shortened to "rfactor".

operator	relocation factor(s) of operand(s)	relocation factor of result	example
↑	all operands absolute	absolute	2↑4=16, R1↑1(error)
*	at least one rfactor must be absolute, the other is arbitrary	found by multiplying the value of the absolute operand times the rfactor of the other operand	3*R2 has rfactor of 6 R1*R1(error)
/	all operands absolute	absolute	4/2=2, R1/1(error)
+ - (unary and binary)	arbitrary rfactors	found by applying operator to the relocation factors of the operands	R1+R2 has relocation factor of 3
< <= = # >= >	arbitrary relocation factors, but must be equal	absolute	R1=R1 is true R2>R1(error)
& ! % @	all operands absolute	absolute	7&3=3, @R1(error)

17) The table below lists all the operators that may be used in NARP expressions, along with their precedence (the higher the precedence, the tighter the operator binds its operands) and some comments.

Operator	Precedence	Comment
↑	6	exponentiation; exponent must be ≥ 0
*	5	multiplication
/	5	integer division
+ (u)	4	unary plus (effectively a nop)
- (u)	4	negation
+	4	addition
-	4	subtraction
<	3	less than
<=	3	less than or equal to
=	3	equal to
#	3	not equal to
>=	3	greater than or equal to
>	3	greater than
@	2	logical not
&	1	logical and
!	0	logical or
%	0	logical exclusive or

18) At the moment, the following ARPAS opcodes are undefined in NARP (there is more on these opcodes in subsequent pages): ORG, RAD, ENTRY

19) TEXT, ASC: The ARPAS option of specifying the length of the string instead of enclosing it in quotes is not allowed. However, the string delimiting character is not restricted to a quote, but may be any printing character except blank or semicolon. Thus TEXT %QUOTE MARK: '% is legal. Of course, the first character encountered is taken as the delimiting character. Within a string, blanks, commas, and semicolons have no special meaning; they are treated just like the other characters in the string.

20) EQU: The expression must be defined (the ARPAS manual also says this is necessary, but in many cases it isn't because ARPAS has two passes). The relocation factor of the expression must be in the range [-15,15].

21) EXT: In the option <symbol> EXT, the symbol must be defined (again this is what the ARPAS manual says, but the two-pass nature of ARPAS makes it possible to ignore this). In the option <symbol> EXT <expression>, it is not necessary that the symbol be defined, but the expression must be defined (its relocation factor is arbitrary). At present ENTRY is not implemented. See 40 below for a detailed discussion of symbol definitions, both external and otherwise.

22) OPD, POPD: Because of the different opcode classification scheme in NARP, the format of an OPD is rather different than in ARPAS:

syntax: <symbol> OPD <value>[,<op sit>[,<shiftk>]]
semantics:
<symbol> - becomes defined as an opcode; if the symbol is already an opcode than 'W' is typed as a warning and the previous definition is overwritten.

Note: All of the following may be arbitrary expressions, but they must be defined and absolute. If an optional expression does not appear then the value 0 is assumed.

<value> - computed mod 2^{24} and used as the value for the opcode (see important note below).
<op sit> - operand situation: must have a value of 0,1, or 2, with the following meanings:

0 - operand optional
1 - no operand
2 - operand required

<shiftk> - shift kludge; must have a value of 0 or 1 with the following meanings:

0 - non-shift instruction
1 - shift instruction

Note: Although an opcode that takes operands can be defined with bits b10-b23 set, the user must be careful of what he is doing. In particular, if such an opcode appears in an instruction which contains a literal or an undefined value then bits b10-b23 of the opcode will be set to zero.

Warning: The usual ARPAS opcode definition of <value>,1,1 will result in a NARP opcode which takes no operands. Thus such an ARPAS program will cause no error messages when assembled by NARP, but it will surely not run when loaded.

23) ORG: This does not exist in NARP. There is no reasonable way in which a one-pass assembler (that doesn't assemble directly into core) can handle ORG.

24) RAD: This does not exist in NARP because of the freer relocation rules that do away with (R).

25) IDENT: Only the first six characters of the preceding symbol and the word 'IDENT' are printed.

26) The concatenation symbol '.' used in ARPAS is replaced by '.&' in NARP. This makes it possible to use the character '.' in macro definitions, in particular within strings (of course '.&' within a string will get removed). The ordinary use of '.&' is to separate a reference to a preceding alphanumeric character. In all other cases '.&' is superfluous, although legal. During a macro definition, '.&' is detected at all levels ("level" here refers to the nesting of MACRO - ENDM pairs), but is only removed at the top level. Thus the following will work fine, even if D(I) is the null string:

```
A   MACRO   D
B   MACRO   E
    TEXT    'ABC.&D(I)E(J)'
    ENDM
    ENDM
```

27) Whole-line comments (i.e., lines of text beginning with an asterisk) are not saved as part of a macro definition, but comments following instructions are. Thus it behooves the programmer to use these comments sparingly as they only gobble up core space.

28) A dummy subscript may not have value -1. Instead of following a macro call with an asterisk to set the indirect bit on some argument, the '←' convention should be used. An asterisk following a macro call or a directive is an error.

29) The conventions concerning a dummy subscript of value zero are somewhat different. First of all, D(0) and D(1-1) are completely equivalent as far as NARP is concerned (only the subscript <u>value</u>, not its <u>syntax</u>, is considered), and the appearance of either of them has no effect whatever on whether a symbol in the label field of the macro call gets defined. An occurrence of D(0) is replaced by the label field of the macro call during expansion; if this field is empty, D(0) expands as the null string. In any event, D(0) will be at most seven characters long, namely the first six characters of the symbol in the label field preceded by '$' if the label field begins with a '$'.

30) Dummy subscripts (including <u>all</u> the subscripts appearing between '(' and ')', e.g., e2 and e3 as well as e1 in D(e1$e2,e3)), generated symbol subscripts, and expressions between '($' and ')' may be arbitrary NARP expressions. Furthermore, these expressions may contain references to dummy variables, generated symbols, and value-to-digit-string expressions. Thus ($4+D(I*D(3))) is legal.

    Any undefined symbols occurring in these expressions are treated as defined symbols with the value -1.

31) The construct D() no longer expands to all the arguments of a macro call, but instead expands to the first argument only (<u>without</u> enclosing parentheses). To achieve the effect that D() has in ARPAS, use D(,) in NARP.

32) NARP allows more syntactical forms of references to dummy variables than ARPAS does. Before describing all the possible combinations, a few conventions are convenient:

a) In the following, "argument" will refer to the character string, as given in the macro call, <u>after possible enclosing parentheses have been removed</u>.

b) The number of arguments supplied at the call is n ($n \geqq 0$).

c) The number of characters in an argument i is n(ei).

d) The structure ei for i an integer stands for an expression (its value stands for some argument usually, so ei will be used somewhat ambiguously to stand for an expression or the value of an expression).

With the above in mind, we consider the three kinds of references to dummy variables:

i.) D(e1)

This expands to argument e1 (which may be the null string), where $0 \leqq e1 \leqq n$.

Special notation: D() = D(1)

ii.) D(e1,e2)

If e1 > e2 then this expands to the null string (the range of values of e1 and e2 is arbitrary), otherwise this expands to argument e1 through e2, where $o \leqq e1 \leqq e2 \leqq n$, with each

argument enclosed in parentheses and a comma inserted between each argument. For example, D(3,3) = (D(3)).

Special notation: D(,) = D(1,n)
D(,e1) = D(1,e1)
D(e1,) = D(e1,n)

iii.) D(e1$e2,e3)

In all cases, $0 \leq e1 \leq n$ must be true. If $e2 > e3$ then this expands to the null string (range of values of e2 and e3 is arbitrary), otherwise it expands to characters e2 through e3 of argument e1.

Special notations: D(e1$,) = D(e1$1,n(e1))
D(e1$,e2) = D(e1$1,e2)
D(e1$e2,) = D(e1$e2,n(e1))
D(e1$e2) = D(e1$e2,e2)
D(e1$) = D(e1$1) = D(e1$1,1)
In any of the above six forms, e1 may be missing; if so 1 is assumed.

Note on special notations: A general rule which will help in remembering what the special notations mean is the following: "Whenever an expression is missing from a form, the value 1 is assumed, unless the expression is missing from a place where an upper bound is expected (as in D(3,) or D(3$2,)), in which case the largest "reasonable" value is assumed."

The observant reader will have noted that in the above description of the form D(e1$e2,e3), no mention was made of the bounds of an e2 and e3 in case $e2 \leq e3$. This was intentional, since by choosing e2 and e3 appropriately, sneaky

things can be done, although they should not be played with lightly since they depend on the implementation of macro calls in NARP. When a macro call is made, the arguments are laid out in core in one contiguous string, with each argument surrounded by parentheses and followed by a comma. For example $BETA AMAC (GAMMA),(⊥DELTA⊥EPSLON⊥), ZETA causes the following argument string to be laid out in core: ($BETA),(GAMMA),(⊥DELTA⊥EPSLON⊥),(ZETA), Each argument has a pointer associated with it which points to the left parenthesis preceding the argument, and when a form like D(e1$e2,e3) is expanded, the values of e2 and e3 are simply added to e1's pointer, delimiting the string which is to replace the dummy reference. By picking e2 and e3 appropriately, this string may include parts of argument e1-1 and e1+1 (as well as argument e1) or even the entire argument string. The only restriction on e2 and e3 is that when added to the pointer for e1, the resulting pointer must not be outside the entire argument string for the macro call.

Examples: (Assuming the call shown above is being processed)

D(1$-1,7) = , (GAMMA),
D(2$-4,4) = MA),(⊥DEL
D(2$18,21) = ZETA
D(1$-9,-1) is an error because the -9 points one character to the left of the entire argument string
D(2$-16,23) = ($BETA),(GAMMA),(⊥DELTA⊥EPSLON⊥),(ZETA),

Although this feature may have limited uses, it is there for the programmer to utilize if he finds a use for it.

33) The format of an argument given to a macro when it is called may be slightly different in NARP than in ARPAS ("may be" is intentional, since we have not been able to discover the

precise ARPAS format). The essential thing is this: any blanks, commas, semicolons, or parentheses occurring between single quotes ("between" here means between an "odd-quote" and an "even-quote", where the first quote encountered is odd, the next is even, etc., thus B and D are between single quotes in the following, but A, C, and E aren't: A'B'C'D'E) are treated exactly like other characters between single quotes, i.e., they do not serve as terminators, separators, or the like. In effect, when the argument collector in NARP is collecting arguments for a macro call, the occurrence of a single quote causes it to stop looking for special characters except for quotes (and, of course, carriage return, which is an absolute terminator). Thus, in the following, when a blank, comma, semicolon, or parenthesis is referred to, it is understood that the character is <u>not</u> between single quotes.

The argument string for a macro call has the following format:

<arg>,<arg>,...,<arg> <terminator> where <terminator> is a blank, semicolon, or carriage return. There are essentially three forms of <arg>:

i.) <arg> may be the null string.

ii.) If the first character of <arg> <u>is not</u> a left parenthesis then <arg> is a string of characters not containing blank, comma, semicolon, or carriage return (remember: blanks, commas, and semicolons may appear in <arg> if they are between single quotes).

iii.) If the first character of <arg> <u>is</u> a left parenthesis, then <arg> does not terminate until a blank, comma, or semicolon is encountered <u>after</u> the right parenthesis which matches the initial left parenthesis ("matches" means that all left and right parentheses in the argument are noted and paired off with each other so that a nested parenthesis structure is possible). Of course, a carriage return at any point

immediately terminates <arg>. Again, remember that blanks, commas, semicolons, and parenthesis between single quotes are ignored when <arg> is being delimited. The initial left parenthesis and its matching right parenthesis (note that this right parenthesis need not be the last character of <arg>) are removed from <arg> before it is transmitted to the macro.

```
Examples:   AMAC   (,␣;␣,),,'HOUSE,␣ROGER'
                 D(1) = ,␣;␣,
                 D(2) is the null string
                 D(3) = 'HOUSE,␣ROGER'
            AMAC   ,(PAR(STRING'),'PAR))MORE,AB'␣␣'C
                 D(1) is the null string
                 D(2) = PAR(STRING'),'PAR)MORE
                 D(3) = AB'␣␣'C
```

34) There is no limit on the number of arguments that can be given to a macro (except the size of the core, of course).

35) When constructing a generated symbol, the digit string formed is preceded by one zero. Thus the first time

```
A     MACRO   D,G,3
G(2)  NOP
      ENDM
```

is expanded, G(2) becomes GØ2. The second time it will become GØ5. Since only the first six characters of a symbol are meaningful, the user should keep the generated symbol very short to avoid nasty problems. A generated symbol subscript must be within the range [1,m], where m is the upper limit specified in the macro head (note: $1 \le m \le 1023$ must be true).

36) In the value-to-digit-string conversion, if the value is negative then the digit string is preceded by a minus sign.

37) NARG may only appear within a macro body, but it is legal within <u>any</u> macro body (i.e., even if no dummy variable was specified by a given macro, NARG is still legal within that macro and yields the value zero).

38) NCHR has been changed so that its operand has precisely the same format as an argument to a macro. Thus, the operand ends when a carriage return is encountered, or on the first blank, comma, or semicolon not within single quotes <u>unless</u> the first character of the operand is a left parenthesis. In the latter case, blanks, commas, and semicolons are shielded as described above in the discussion of macro arguments (see 33). By scanning for NCHR and enclosing its operands in parentheses, most ARPAS programs can be easily converted to NARP programs as far as NCHR is concerned. The only case for which this will not work is when the operand contains unmatched parentheses that are not within single quotes.

39) The RPT option RPT <expression> has been extended to RPT <expression>[,<increment list>], where <increment list> is of the form (<symbol>=<e1>[,<e2>]) (...) ... (...) Note, however, that the expression is evaluated <u>before</u> the increment list is processed, so its value should not depend on symbols initialized in the increment list.

Example:
```
        RPT     4,(J=2,3)
        DATA    J↑3
        ENDR
```
When expanded results in the following values:
```
           8
         125
         512
        1331
```
The increment list of any RPT or CRPT option may be of any length; no limit is set as in ARPAS.

40) Symbol definitions and external symbols:
Symbols are defined in three ways: By being assigned values with EQU directives (or equivalently, by appearing in an RPT or CRPT increment list), by appearing as labels, and by being used with the EXT directive in a certain way. Symbols may also be declared as external in two ways, by preceding them with $ when they are defined, or by giving them as parameters to the directive EXT after they are defined. These cases are discussed in greater detail below:

a) Symbol defined as a label: If the symbol is already defined, either as a label or by EQU, the error message 'D' is typed; the old definition is completely replaced by the new one.

b) Symbol defined by EQU: If the symbol is already defined as a label than the error message 'D' is typed and the old definition is completely replaced by the new one; if the symbol is already defined by EQU then its value is changed, and if a $ is present the symbol is marked as external; the operand of EQU must be defined and must have an rfactor in the range [-15,15].

c) Symbol defined by EXT: See e.) below.

d) Declared external by $: For a label this is obvious; for an EQU'ed symbol, a $ need appear only once, successive EQU's of the symbol will preserve the external mark.

e) Declared external by EXT: Two cases:
   i.) EXT has no operand: The symbol in the label field is simply marked as external; it must be a defined symbol, but it may have already

been marked as external or may even have a $ preceding it.

ii.) EXT has an operand: The operand must be a defined expression; the symbol is immediately output as an external symbol with value the same as the operand value; <u>no local definition of the symbol is made</u>, in fact no table look-up or addition to the table occurs.

Note: ARPAS and NARP output external symbol definitions at different times; it is possible that this can have an effect on a program if the user has done something kludgy. Except for case ii.) under e.) above, NARP outputs no external definitions until the END directive is encountered. ARPAS, however, outputs external definitions as soon as it can. Thus,

```
$A   EQU   3
      ⋮
 A   EQU   4
      ⋮
     END
```

will cause ARPAS to output an external definition of A with value 3, while NARP will output an external definition of A with value 4.

41) It is conceivable that the manner in which undefined expressions are handled by NARP could lead to difficulties in very obscure cases which are at best vaguely defined anyway. When NARP encounters an undefined expression which involves more than a single undefined symbol, the expression is saved until every undefined symbol in it becomes defined. At the moment when this happens, the expression is evaluated.

Thus

```
            DATA      A + B
    A       EQU       0
    A       EQU       1
    B       EQU       2
            END
```

will cause a data word of value 3 (not 2) to be output.

42) Operating NARP: When started, NARP asks for the specification of a source file, an object file, and an optional text file. Only one confirmation character is needed, namely, a carriage return at the end of the object file specification. Then NARP immediately begins processing, typing only IDENT's and error messages until the END directive is encountered (don't be surprised when NARP types an IDENT immediately after it starts processing; remember that it is one-pass).

At the end of the assembly, a line of the following form is typed:

```
2 SEC    3 ERRORS    101(65)WORDS    (S:413,0:10,L:87,M:2033,U:73)
```

2 SEC: This is the time required for assembly as measured by BRS 88. Timing begins after all files are opened and ends before any file is closed.

3 ERRORS: The number of error messages typed during the assembly.

101(65)WORDS: The value of the location counter when the END directive is encountered (first in octal, then in decimal).

S:413	413 symbols in the symbol table.
O:10	10 programmer-defined opcodes (excluding macros) in the opcode table
L:87	87 literals in the literal table
M:2033	2033 machine words of defined macros
U:73	73 words of undefined expressions in expression table (currently this is the maximum size attained by the undefined expression table during the assembly; there is as yet no garbage collection for this table).

43) The three most important tables in NARP are the main table (which contains all symbols, opcodes, and literals, each occupying 4 words per entry), the string storage (which contains all macro definitions and is used for storing repeat blocks and argument strings to macros; characters are packed 3 to a word), and the undefined expression table. Currently these tables have the following sizes:

main table	5000	(1250 entries)
as	2250	
expr table	900	

Using these figures and the information printed out at the end of an assembly, the user can see how close he is to overflowing the tables (remember that there are 191 pre-defined opcodes in the main table, so the user can only create 1059 new entries). Currently there is no garbage collection in the string storage.

44) At the end of an assembly, after typing the line of information mentioned above, all undefined symbols are listed.

1.0 Introduction

NARP (new ARPAS) is a one-pass assembler for the SDS 940 with literal, subprogram, conditional assembly, and macro facilities. The source language for NARP, primarily a one-for-one representation of machine language written in symbolic form, is very similar to that for ARPAS (another assembler for the 940), but there are notable exceptions making it necessary to do a certain amount of transliteration to convert an ARPAS program to a NARP program. No further mention will be made of ARPAS in this manual; for more details see ARPAS, Reference Manual for Time-Sharing Assembler for the SDS 930, Doc. No. R-26, February 24, 1967.

To motivate the various facilities of the assembler, the following pseudo-historical development of assembly languages is presented.

1.1 Pseudo-history of assembly languages

A program stored in the main memory of a modern computer consists of an array of tiny circular magnetic fields, some oriented clockwise, others oriented counterclockwise. Obviously, if a programmer had to think in these terms when he sat down to write a program, few problems of any complexity would be solved by computers, and the cost of keeping programmers sane would be prohibitive. To remedy this situation, utility programs called assemblers have been developed to translate programs from a symbolic form convenient for human use to the rather tedious bit patterns that the computer handles. At first these assemblers were quite primitive, little more than number converters, in fact. Thus, for example:

Tag	Opcode	Address
ø	76	øø4øø
ø	55	øø4ø1
ø	35	øø4ø2

would be converted into three computer instructions which would add together the contents of cells 4ØØ and 4Ø1 and place the result in cell 4Ø2. An assembler for doing this type of conversion is trivial to construct.

After a time, some irritated programmer who could never remember the numerical value of the operation "load the A register with the contents of a cell of memory" decided that it would not be too difficult to write a more sophisticated assembler which would allow him to write a short mnemonic word in place of the number representing the hardware operation. Thus, the sequence of instructions shown above became:

```
Ø LDA ØØ4ØØ
Ø ADD ØØ4Ø1
Ø STA ØØ4Ø2
```

This innovation cost something, however, namely the assembler had to be more clever. But not much more clever. The programmer in charge of the assembler simply added a table to the assembler which consisted of all the mnemonic operation names (opcodes) and an associated number, namely the numerical value of the opcode. When a mnemonic name, say 'ADD', was encountered by the assembler during the conversion of a program, the opcode table was scanned until the mnemonic name was found; then the associated numerical value (in this case, 55) was used to form the instruction. Within a month, no programmer could tell you the numerical value of XMA.

In a more established field, the innovation of these mnemonic names would have been quite enough for many years and many theoretical papers. However, programmers are an irritable lot, and furthermore, are noted for their ability to get rid of sources of irritation, either by writing more clever programs or by asking the engineers to refrain from making such awkward machines. And the use of numbers to represent addresses in memory was a large source of irritation. To see this we need another example:

```
Ø CLA
Ø LDX ØØ4ØØ
2 STA ØØ5Ø7
Ø BRX ØØ3ØØ
```

Assuming cell 400 contains -7, this sequence stores zeroes in cells 500 through 506 provided that the sequence is loaded in memory so that the STA instruction is in cell 300 (otherwise, the BRX instruction would have to be modified). This was the crux of the problem: Once a program was written, it could only run from a fixed place in memory and could only operate on fixed cells in memory. This was especially awkward when a program was changed, since inserting an instruction anywhere in a program would generally require changes in many, many addresses. One day a clever programmer saw that this problem could be handled by a generalization of the scheme used to handle opcodes, namely, let the programmer use symbolic names (symbols) for addresses and have the assembler build a table of these symbols as they are defined and then later distribute the numerical values associated with the symbols as they are used. Thus the example becomes:

```
        CLA
        LDX     TABLEN
LOOP    STA     TABEND,2
        BRX     LOOP
```

(Note that at the same time the programmer decided to move the tag field to after the address field (simply for the sake of readability) and to even dispense with it entirely in case it was zero.) The assembler now has two tables, the fixed opcode table with predefined names in it, and a symbol table which is initially empty. There is also a special cell in the assembler called the location counter (LC) which keeps track of how many cells of program have been assembled; LC is initially zero. There is another complication: In the above example, when the symbol TABLEN is encountered, it may not be defined yet, so the assembler doesn't know what numerical value to replace it with. There are several clever ways to get around this problem, but the most obvious is to have the assembler process the program to be assembled twice. Thus, the first time the assembler scans the program it is mainly interested in the symbol definitions in the left margin (a symbol used to represent a memory address is called a label). In our example, when LOOP is encountered, it is stored in the symbol table and given the value 2 (because

it is preceded by two cells; remember that LC keeps track of this). At the end of pass 1, all symbols defined in the program are in the symbol table with numerical values corresponding to their addresses in the memory. So when pass 2 begins, the symbol table is used exactly as the opcode table is used, namely, when, for example, LOOP is encountered in the BRX instruction above, it is looked up in the symbol table and replaced by the value 2. If the program should later be changed, for example to

```
        CLA
        LDB     EIGHT
        LDX     TABLEN
LOOP    STP     TABEND,2
        EAX     1,2
        BRX     LOOP
```

then the assembler will automatically fix up LOOP to have the value 3 (because of the inserted LDB instruction) and will convert BRX LOOP to BRX 3 instead of to BRX 2 as before. Thus, the programmer can forget about adjusting a lot of numerical addresses and let the assembler do the work of assigning new values to the symbols and distributing them to the points where the symbols are used. In addition to the greater flexibility achieved, symbols with mnemonic value can be used to make the program more readable.

The use of symbols to stand for numerical values which are computed by the assembler and not the programmer is the basic characteristic of all assembly languages. Its inception was a fundamental breakthrough in machine language programming,dispensing with much dullness and tedium. And a new breed of programmer was born: the assembler-writer. To justify his existence, the assembler-writer began to add all sorts of bells and whistles to his products; the primary ones are discussed in the next section (with reference to NARP).

1.2 Assembly languages: some basic constituents and concepts

Times: assembly time: when a program in symbolic form is converted by an assembler to binary (relocatable) program form.

load time: when a binary program is converted by a loader to actual machine language in the main memory of the computer.

rum time: when the loaded program is executed.

source program --assembler--> binary program --loader--> object program

Expressions: The idea of using a symbol to stand for an address is generalized to allow an arithmetic expression (possibly containing symbols) to stand for an address. Thus, some calculations can be performed at assembly time rather than at run time, making programs more efficient.

Literals: Rather than writing LDA M1 and somewhere else defining M1 to be a cell containing -1, the literal capability allows the programmer to write the contents of a cell in the address field instead of the address of a cell. To indicate this, the expression is preceded by '='. The assembler automatically assigns a cell for the value of the expression (at the end of the program):

```
        CLA
        LDB     =8
        LDX     =-16*2
LOOP    STP     TABBEG+16*2,2
        EAX     1,2
        BRX     LOOP
```

Relocation: A relocatable program is one in which memory locations have been computed relative to the first word or origin of the program. A loader (for this assembler, DDT) can then place the assembled program into core beginning at whatever location may be specified at load time. Placement of the program involves a small calculation. For example, if a memory reference is to the nth word of a program, and if the program is loaded beginning at location k, the loader must transform the reference into absolute location n+k. This calculation should not be done to each word of a program since some machine instructions (shifts, for example) do not refer to memory locations. It is therefore necessary to inform the loader whether or not to relocate the address for each word of the program. Relocation information is determined automatically by the assembler and transmitted as a relocation factor (rfactor). Constants or data may similarly

require relocation, the difference here being that the relocation calculation should apply to all 24 bits of the 940 word, not just to the address field. The assembler accounts for this difference automatically.

Subprograms and external symbols: Programs often become quite large or fall into logical divisions which are almost independent. In either case it is convenient to break them into pieces and assemble (and even debug) them separately. Separately assembled parts of the same program are called subprograms (or packages). Before a program assembled in pieces as subprograms can be run it is necessary to load the pieces into memory and link them. The symbols used in a given subprogram are generally local to that subprogram. Subprograms do, however, need to refer to symbols defined in other subprograms. The linking process takes care of such cross references. Symbols used for it are called external symbols.

Directives: A directive (pseudo-opcode is a message to the assembler serving to change the assembly process in some way. Directives are also used to create data:

```
        LIST
MESSAGE TEXT    'THIS IS A PIECE OF TEXT'
START   LDA     ALPHA
```

The LIST directive will cause the program to be listed during assembly, while the TEXT directive will cause the following text to be stored in memory, four characters to a word.

Conditional assembly: It is frequently desirable to permit the assembler to either assemble or skip a block of statements depending on the value of an expression at assembly time; this is called conditional assembly. With this facility, totally different object programs can be generated, depending on the values of a few parameters.

Macros: A macro is a block of text defined somewhere in the program and given a name. Later references to this name cause the reference to be replaced by the block of text. Thus, the macro facility can be thought of as an abbreviation or shorthand notation for one or more assembly language statements. The macro

facility is more powerful than this, however, since a macro may have formal arguments which are replaced by actual arguments when the macro is called.

One-pass assembly: Instead of processing a source program twice as was described above (section 1.1), NARP accomplishes the same task in one scan over the source program. The method used is rather complex and is not described in this document.

2.0 Basic constituents of NARP

2.1 Character set

All the characters listed in Appendix B have meaning in NARP except for '?' and '\'. The following classification of the character set is useful:

letter:	A-Z
octal digit:	0-7
digit:	0-9
alphanumeric character:	letter or digit or colon
terminator:	, ; blank CR (denotes carriage return)
operator:	! # % & * + - / < = > @ ↑
delimiter:	" $ ' ( ) [ ] . ←

The multiple-blank character (135_8) may appear anywhere that a blank is allowed. All characters with values greater than 77_8 are ignored except for multiple-blank character (135_8) and carriage return (155_8).

2.2 Statements and format

The logical unit of input to NARP is the statement, a sequence of characters terminated by a semi-colon or a carriage return. There are five kinds of statements:

empty: A statement may consist of no characters at all, or only of blank characters.

comment: If the very first character of a statement is an asterisk, then the entire statement is treated as a comment containing information for a human reader. Such statements generate no output.

The format for the next three kinds of statements is split into four fields:

label field: This field is used primarily for symbol definition; it begins with the first character of the statement and ends on the first non-alphanumeric character (usually a blank).

<u>opcode field</u>: This field contains a directive name, a macro name, or an instruction (i.e., any opcode other than a directive or macro). The field begins with the first non-blank character after the label field and terminates on the first non-alphanumeric character; legal terminators for this field are blank, asterisk, semi-colon, and carriage return.

<u>operand field</u>: The operand for an instruction, macro, or directive appears in this field, it begins with the first non-blank character following the opcode field and terminates on the first blank, semi-colon, or carriage return. Note that a statement may terminate before the operand field.

<u>comment field</u>: This field contains no information for NARP but may be used to help clarify a program for a human reader. The field starts with the first non-blank character after the operand field (or after the opcode field if the opcode takes no operand) and ends on a semi-colon or carriage return.

Now we continue describing the kinds of statements:

instruction: If the opcode field of a statement does not contain a directive name or a macro name, then the statement is an instruction. An instruction usually has an expression as an operand and generates a single machine word of program. See section 3 for a detailed description of instructions.

directive: If a directive name appears in the opcode field, then it is a directive statement. The action of each directive is unique and thus each one is described separately (in section 4).

macro: A macro name in the opcode field of a statement indicates that the body of text associated with the macro name should be processed (see section 5).

Example of various kinds of statements:

```
*  FOLLOWING ARE TWO DIRECTIVES (MACRO,ENDM) WHICH DEFINE
*  THE MACRO SKAP
SKAP MACRO;     SKA =4B7;    ENDM
```

```
*  NOW SKAP IS CALLED:
        LDA ALPHA
        SKAP;   BRU BAD      IF NEGATIVE THEN ERROR
OKAY    ADD BETA    NOW A=ALPHA+BETA;    BRU GOOD
```

In subsequent sections the details of instructions, directives, and macros will be explained, but first some basic constituents and concepts common to all of these statements will be discussed.

2.3 Symbols, numbers, and string constants

Any string of alphanumeric characters not forming a number is a symbol, but only the first six characters distinguish the symbol (thus Q12345 is the same symbol as Q123456). Note that a symbol may begin with a digit, and that a colon is treated as a letter (as a matter of good programming practice, colons should be rarely used in symbols, although they are often useful in macros and other obscure places to avoid conflicts with other names). In the next section the definition and the rfactors of symbols are discussed.

A number is any one of the following:

a) A string of digits

b) A string of digits followed by the letter 'D'

c) A string of digits followed by the letter 'B'

d) A string of digits followed by the letter 'B' followed by a single digit.

A D-suffix indicates the number is decimal, whereas a B-suffix indicates an octal number. If there is no suffix, then the current radix is used to interpret the number (the current radix is initially 10 but it may be changed by the OCT and DEC directives). If the digit 8 or 9 is encountered in an octal number, then an error message is typed. If the value of a number exceeds $2^{23}-1$ overflow results; NARP does not check for this condition, and in general it should be avoided. A B-suffix followed by a digit indicates an octal scaling; thus, 74B3=74ØØØB.

Examples:

symbols: START 1M CALCULATE 14D2 14B10

numbers: 14 18D 773B 777B5 13B9

A string constant is one of the following:

a) A string of 1 to 3 characters enclosed in double quotes (").

b) A string of 1 to 4 characters enclosed in single quotes (').

In the first case the characters are considered to be 8 bits each (thus only 3 can be stored in one machine word), while in the second case they are considered to be 6 bits each. In both cases, strings of less than the maximum length (3 or 4, as the case may be) are right-justified. Thus

'A' = '␣␣␣A' = "A" = "␣␣A"

where ␣ denotes a blank. If a string constant is too long, then an error message is typed and only the first 3 (or 4) characters are taken. Normally string constants are not very useful in address computation, but are most often used as literals:

```
LDA     WORD
SKE     ='GO'
BRU     STOP
```

Both numbers and string constants are absolute, i.e., their rfactor is zero.

2.4 Symbol definitions

Since NARP is a one-pass assembler, the statement that a symbol or expression is "defined" usually means that it is defined at that instant and not somewhere later in the program. Thus, assuming ALPHA is defined nowhere else, the following

```
BETA    EQU   ALPHA
ALPHA   BSS   3
```

is an error because the EQU directive demands a defined operand and ALPHA is not defined until the next statement. This convention is not strictly adhered to, however, since sometimes the statement "XYZ is not defined" will mean that XYZ is defined nowhere in the program.

A symbol is defined in one of two ways: by appearing as a label or by being assigned a value with an EQU directive (or

equivalently, by being assigned a value by NARG, NCHR, EXT (see below), or by being used in the increment list of a RPT or CRPT statement). The latter type of symbols are called equated symbols.

Labels: If a symbol appears in the label field of an instruction (or in the label field of some directives) then it is defined with the current value of the location counter (rfactor=1). If the symbol is already defined, either as a label or as an equated symbol, the error message '(Symbol) REDEFINED' is typed and the old definition is completely replaced by the new one.

Equated symbols: These symbols are usually defined by EQU, getting the value of the expression in the operand field of the EQU directive. This expression must be defined and have an rfactor in the range [-15,15]. If the symbol has been previously defined as a label, then the error message '(Symbol) REDEFINED' is typed and the old definition is completely replaced by the new one; if the symbol has already been defined as an equated symbol, then no error message is given, but the old value and rfactor are replaced by the new ones. Thus, an equated symbol can be defined over and over again, getting a new value each time.

A defined symbol is always local, and may also be external. If a symbol in package A is referred to from package B, it must be declared external in package A. This is done in one of the following ways:

Declared external by $: If a label or equated symbol is preceded by a $ when it is defined, then it is declared external.

```
$LABEL1   LDA   ALPHA
LABEL2    STA   BETA    LABEL2 IS LOCAL ONLY
$GAMMA    EQU   DELTA
```

Declared external by the EXT directive: There are two cases:
i) EXT has no operand: The symbol in the label field is declared external; it must be a defined symbol, but it may have already been declared external or may even have a $ preceding it.
ii) EXT has an operand: This case is treated exactly like the case: $label EQU operand.

Certain symbols are pre-defined in NARP, i.e., they already have values when an assembly begins and need not be defined by the programmer:

:ZERO: This is a relocatable zero (i.e., value = 0, rfactor = 1).

:LC: This symbol is initially zero (rfactor=1) and remains so until the END directive is encountered and all literals are output, at which time it gets the value of the location counter. See the description of FREEZE for a discussion of the use of this symbol.

Syntactically this is not a symbol, but semantically it acts like one. At any given moment, * has the value of the location counter (rfactor=1), and can thus be used to avoid creating a lot of local labels.

Thus
```
        CLA;    LDX     LENGTH
   LOOP STA     TABLE,2;   BRX    LOOP
```
can be written as
```
        CLA;   LDX LENGTH;   STA TABLE,2;   BRX   *-1
```

If a given symbol is referred to in a program, but is not defined when the END directive is encountered then it is assumed that this symbol is defined as external in some other package. Whether this is the case cannot be determined until the various packages have been loaded by DDT. Such symbols are called "undefined symbols" or "external symbol references." It is possible to perform arithmetic upon them (e.g., LDA UNDEF+1); an expression in post-fix Polish form will be transmitted to DDT.

2.5 Expressions and literals

Loosely speaking, an expression is a sequence of constants and symbols connected by operators. Examples:

```
100-2*ABC/[ALPHA+BETA]
GAMMA
F>=Q
```

Following is the formal description (in Backus normal form) of a NARP expression:

```
<primary>::=<number>|<string constant>|<symbol>| * |[<expr2>]
<expr1>::=<primary>|<primary> <binary operator> <expr1>
<expr2>::=<expr1>|<unary operator> <expr1>
<expression>::=<expr2>|<literal operator> <expr2>

<binary operator>::=↑|*|/|+|-|<|<=|=|#|>=|>|&|!|%
<unary operator>::=+|-|@
<literal operator>::= =
```

The main point of the above syntax is that two operators may never be adjacent (except for a unary operator following a literal operator), so A &@B is illegal (write it as@B & A). The literal operator is rather special, only being allowed to appear once in a given expression, and only as the first character of the expression. Literals are discussed in greater detail below.

The value of an expression is obtained by applying the operators to the values of the constants and symbols, evaluating from left to right except when this order is interrupted by the precedence of the operators or by square brackets*([]); the result is interpreted as a 24-bit signed integer. The following table describes the various operators and lists their precedences (the higher the precedence, the tighter the operator binds its operands):

---

*not parentheses!

Operator	Precedence	Comment	
↑	6	exponentiation; exponent must be ≥ 0	
*	5	multiplication	
/	5	integer division	
+ (u)	4	unary plus	
- (u)	4	negation	
+	4	addition	
-	4	subtraction	
<	3	less than	
<=	3	less than or equal to	result of operation is
=	3	equal to	0 if relation is false,
#	3	not equal to	otherwise 1
>=	3	greater than or equal to	
>	3	greater than	
@ (u)	2	logical not	
&	1	logical and	logical operation
!	0	logical or	applied to all
%	0	logical exclusive or	24 bits

The rfactor of an expression is computed at the same time the value is computed. There are constraints, however, on the rfactors of the operands of certain operators, as shown in the table below: (Note: R1 is a symbol with an rfactor of 1, R2 is a symbol with an rfactor of 2).

operator	relocation factor(s) of operand(s)	relocation factor of result	examples
↑ & ! /	all operands absolute	absolute	2↑4=16, R1↑1(error) 7&3=3, 6&R1(error) 4/2=2, R1/1(error)
*	at least one rfactor must be absolute, the other is arbitrary	found by multiplying the value of the absolute operand times the rfactor of the other operand	3*R2 has rfactor of 6, R1*R1(error)
< <= = # >= >	arbitrary relocation factors, but must be equal	absolute	R1=R1 is true R2>R1(error)
+ - (unary and binary)	arbitrary rfactors	found by applying operator to the relocation factors of the operands	R1+R2 has relocation factor of 3

The final rfactor of an expression must be in the range [-8191, 8191].

If an expression contains an undefined symbol or if it is a literal, then the entire expression is undefined.

Although a literal is a special kind of expression, it is often convenient to think of it as a quite separate entity. The use of literals is discussed below.

Programmers frequently write such things as

```
        LDA     FIVE
```

where FIVE is the name of a cell containing the constant 5. The programmer must remember to include the datum FIVE in his program somewhere. This can be avoided by the use of a literal.

```
        LDA     =5
```

will automatically produce a location containing the correct constant in the program. Such a construct is called a literal. When a literal is encountered, the assembler first evaluates the expression and looks up its value in a table of literals constructed for each subprogram. If it is not found in the table, the value is placed there. In any case the literal itself is replaced by the location of its value in the literal table. At the end of assembly the literal table is placed after the sub-program.

The following are examples of literals:

```
=10     =4B6     =ABC*20-DEF/12     ='HELP'
=2>AB   (This is a conditional literal.  Its value will
        be 1 or 0 depending on whether 2>AB at assembly
        time.)
```

Some programmers tend to forget that the literal table follows the subprogram. This could be harmful if the program ended with the declaration of a large array using the statement

```
ARRAY   BSS     1
```

It is not strictly correct to do this, but some programmers attempt it anyway on the theory that all they want to do is to name the first cell of the array. The above statement will do that, of course, but only one cell will be reserved for the array. If any literals were used in the subprogram, they would be placed in the following cells which now fall into the array. This is, of course, an error. Other than this exception, the programmers need not concern himself with the locations of the literals.

2.6 Opcode classification

As mentioned above, there are three types of opcodes: directives, macros, and instructions (those opcodes which are neither directives nor macros). Aside from its type, each opcode has a class which indicates whether it takes an operand.

class Ø: operand optional (e.g., NOP, EXT)
class 1: no operand (e.g., CIA, DEC)
class 2: operand required (e.g., ADD, DATA)

Note that for class Ø opcodes, if the operand is missing, then the comment field must be empty because otherwise the first item in the comment field will be taken as an operand:

```
        NOP                   THIS IS A COMMENT
```

is the same as

```
        NOP     THIS
```

causing THIS to be treated as a symbol. To get around the problem, write

```
        NOP     Ø             THIS IS A COMMENT
```

On the other hand, class 2 opcodes have no operand field at all:

```
        CIA                   THIS IS A COMMENT
```

Although there are instructions and directives of all three classes, there are no class 2 macros.

3.0 Instructions

There are three different syntactical forms of instruction statements, depending on the class of the instruction in the opcode field: (In the following, syntactical elements enclosed in square brackets are optional; they may or may not be present.)

```
class Ø:  [[$]label]  opcode[*]  [operand[,tag]  [comment]]
class 1:  [[$]label]  opcode[*]  [comment]
class 2:  [[$]label]  opcode[*]  operand[,tag]  [comment]
```

Each of the syntactical elements is discussed below:

$: A label preceded by a dollar sign is declared external (see section 2.4).

label : The label is defined with the current value of the location counter (rfactor=1).

opcode : The opcode must be either an instruction which is already defined or a number. If it is a number, then the value (mod 2^9) of the number is placed in bØ-b8 (bit Ø through bit 8) of the instruction, and it is treated as a class Ø opcode (i.e., operand optional).

* : If an asterisk follows immediately after the opcode then b9 (the indirect bit) of the instruction is set.

operand: The operand is an expression which may or may not be defined and which has any rfactor. The expression may be preceded by '/' or '←' (or both in any order); these characters cause the following bits to be set:

/	b1	(index bit)
←	b9	(indirect bit)

Thus:

```
LDA /VECTOR    is the same as    LDA VECTOR,2
STA ←POINTER   is the same as    STA* POINTER
LDA ←/COMPLX   is the same as    LDA* COMPLX,2
```

tag : The tag is an expression which must be defined and absolute. Its value (mod 2^3) is placed in b∅-b2 of the instruction.

comment: The comment does not affect the instruction generated; it may be listed.

In addition to its class, a given opcode is designated as being either a shift instruction or a non-shift instruction. This has nothing to do with whether the action of the instruction involves shifting, but is simply a way of distinguishing between two kinds of instructions. For non-shift instructions, operands are computed mod 2^{14}, while for shift instructions there are two possibilities:

a) If the indirect bit is set by '*' or '←', then the value of the opcode is trimmed so that b10-b23 are zero, and then the instruction is treated as if it were a non-shift instruction.

b) If the indirect bit is not set as above, then the operand is computed mod 2^9; it must be defined and absolute.

4.0 Directives

There are many directives in NARP; although some of them are similar, each in general has its own syntax. Following is a concise summary:

Class	Directive	Use or Function	Section
Mnemonic for instructions:	COPY	Mnemonic for RCH	4.4
Data generation :	DATA	Generate data	4.5
	ASC	Generate text (3 characters per word)	4.1
	TEXT	Generate text (4 characters per word)	4.23
Value declaration :	EQU	Equate a symbol to a value	4.9
	EXT	Define a symbol as external	4.10
	NARG	Number of arguments	5.5
	NCHR	Number of characters	5.5
	OPD	Define an opcode	4.17
	POPD	Define a programmed operator	4.19
Assembler control :	BES	Block ending symbol	4.2
	BSS	Block starting symbol	4.3
	END	End of assembly	4.8
	DEC	Interpret integers as decimal	4.6
	OCT	Interpret integers as octal	4.16
	FRGT	Do not output a specific symbol	4.12
	IDENT	Identification of a package	4.13

Class	Directive	Use or Function	Section
	DELSYM	Do not output any symbols	4.7
	RELORG	Assemble relative with absolute origin	4.20
	RETREL	Return to relocatable assembly	4.22
	FREEZE	Preserve symbols, opcodes, and macros	4.11
	FIILIB	Assemble FORTRAN II library routines	4.105
	GLOBAL	Reverse meaning of $ and EXT	4.128
	LOCAL	Reset meaning of $ and EXT	4.143
Output and listing control	: LIST	Set listing controls	4.14
	NOLIST	Reset listing controls	4.15
	REM	Type out remark	4.21
Conditional assembly and macros	: IF	Begin if body	5.1
	ELSF	Alternative if body	5.1
	ELSE	Alternative if body	5.1
	ENDF	End if body	5.1
	RPT	Begin repeat body	5.2
	CRPT	Begin conditional repeat body	5.2
	ENDR	End repeat body	5.2
	MACRO	Begin macro body	5.4
	LMACRO	Alternative to MACRO	5.4
	ENDM	End macro body	5.4

In the remainder of this section, all directives listed above except for those associated with conditional assembly and macros are described.

4.1 ASC Generate text (3 characters per word)

[[$]label] ASC string [comment]

This directive creates a string of 8-bit characters stored 3 to a word. The string starts in the leftmost character of a word and takes up as many words as needed; if the last word is not filled up completely with characters from the string, then the right end of the word is filled out with blanks. If a label appears, its value is the address of the first word of the string. The syntactical element "string" is usually any sequence of characters (not containing a single quote) surrounded by single quotes. However, the first character encountered after 'ASC' is used as the string delimiter (of course, blanks and semi-colons cannot be used as string delimiters).

Examples:

```
       ASC   'NO SINGLE QUOTES, HERE IS A SEMI-COLON:;'
$ALPHA ASC   $HERE IS A SINGLE QUOTE: '$
```

4.2 BES Block ending symbol

[[$]label] BES expression [comment]

The location counter is incremented by the value of the expression in the operand field and then the label (if present) is given the new value of the location counter. Thus, in effect, a block of words is reserved and the label addresses the first word after the block. The expression must be defined and absolute. This directive is most often used in conjunction with the BRX instruction, as in the following loop for adding together the elements of an array:

```
      LDX  =-LENGTH;  CLA;  ADD ARRAY,2
      BRX  *-1;  STA  RESULT;  HLT
ARRAY BES  LENGTH
```

4.3 BSS Block starting symbol

[[$]label] BSS expression [comment]

This directive does exactly the same thing as BES except that the label (if present) is defined before the location counter is changed. Thus, the label addresses the first word of the reserved block. It should be noted that the expression for both BES and BSS may have a negative value, in which case the location counter is decremented.

4.4 COPY Mnemonic for RCH

[[$]label] COPY $s_1, s_2, s_3, \ldots$ [comment]

(where s_i are symbols from a special set associated with the COPY directive)

The COPY directive produces an RCH instruction. It takes in its operand field a series of special symbols, each standing for a bit in the address field of the instruction. The bits selected by a given choice of symbols are merged together to form the address. For example, instead of using the instruction CAB (04600004), one could write COPY AB. The special symbol AB has the value 00000004.

The advantage of the directive is that unusual combinations of bits in the address field--those for which there exist normally no operation codes--may be created quite naturally. The special symbols are mnemonics for the functions of the various bits. Moreover, these symbols have this special meaning only when used with this directive; there is no restriction on their use either as symbols or opcodes elsewhere in a program. The symbols are:

Symbol	Bit	Function
A	23	Clear A
B	22	Clear B
AB	21	Copy (A) → B
BA	20	Copy (B) → A
BX	19	Copy (B) → X
XB	18	Copy (X) → B
E	17	Bits 15-23 (exponent part) only
XA	16	Copy (X) → A
AX	15	Copy (A) → X
N	14	Copy -(A) → A (negate A)
X	1	Clear X

To exchange the contents of the B and X registers, negate A, and only for bits 15-23 of all registers, one would write

```
COPY   BX,XB,N,E
```

4.5 DATA Generate data

[[$]label] DATA $e_1,e_2,e_3,\ldots$ [comment]

The DATA directive is used to produce data in programs. Each expression in the operand field is evaluated and the 24-bit values assigned to increasing memory locations. One or more expressions may be present. The label is assigned to the location of the first expression. The effect of this directive is to create a list of data, the first word of which may be labeled.

Since the expressions are not restricted in any way, any type of data can be created with this directive. For example:

```
DATA    100,-217B,START,AB*2/DEF,'NUTS',5
```

creates six words.

4.6 DEC Interpret integers as decimal

DEC [comment]

The radix for integers is set to ten so that all following integers (except those with a B-suffix) are interpreted as decimal. When an assembly begins the radix is initialized to ten, so DEC need never be used unless the OCT directive is used.

4.7 DELSYM Do not output any symbols

DELSYM [comment]

If DELSYM appears anywhere in a program being assembled, the symbol table and opcode definitions will not be output by NARP when the END directive is encountered. The main purpose of this directive is to shorten the object code generated by the assembler, especially when the symbols are not going to be needed later by DDT.

4.8 END End of assembly

END [comment]

When this directive is encountered the assembly of the current program terminates. If the LIST directive has been used then various information may be listed, for example undefined symbols.

4.9 EQU Equate a symbol to a value

[$]symbol EQU expression [comment]

The symbol is defined with the value of the expression; if the symbol is already defined, its value and rfactor are changed. The expression must be defined and must have an rfactor in the range [-15,15]. If the symbol has been declared external before or if it has been forgotten (using FRGT) then EQU preserves this information. Thus

```
$ALPHA  EQU  4
ALPHA   EQU  3
```

will cause ALPHA to be declared external but with a value of three at the end of the assembly (provided ALPHA is not changed again before the END directive). See section 2.4 for more discussion of EQU.

4.10 EXT Define a symbol as external

[$]symbol EXT [expression [comment]]

This directive is used to declare symbols as external. See section 2.4 for a discussion of the various cases.

4.105 FIILIB FORTRAN II Library Routines

FIILIB [comment]

Causes an end-of-program word (31062144B) to be outputted between each program in a multiple program assemble. This allows the resultant object file to be loaded by the FORTRAN II load. The directive need only appear in the first program of the multiple program assembly.

4.11 FREEZE Preserve symbols, opcodes, and macros

FREEZE [comment]

Sometimes subprograms share definitions of symbols, opcodes, and macros. It is possible to cause the assembler to take note of the current contents of its symbol and opcode tables and the currently defined macros and include them in future assemblies, eliminating the need for including copies of this information in every subprogram's source language.

When the FREEZE directive is used, the current table boundaries for symbols and opcodes and the storage area for macros is noted and saved away for later use. These tables may then continue to expand during the current assembly. (A separate subprogram may be used to make these definitions; it will then end with FREEZE; END.) The next assembly may then be started with the table boundaries returned to what they were when FREEZE was last executed. This is done by entering the assembler at its "continue" entry point, i.e., by typing in the EXECUTIVE

CONTINUE

Note that the assembler cannot be released (i.e., another subsystem like QED or DDT cannot be used) without losing the frozen information.

In conjunction with the FREEZE directive, the predefined symbol :LC: is useful, especially when writing large re-entrant programs. Following is a three-package program using FREEZE and :LC:.

```
P1      IDENT
        <definitions of macros, opcodes, and global equated
             symbols>
        <definition of working storage (i.e., read-write
             memory)>
        FREEZE
        END

P2      IDENT
        BSS       :LC:-:ZERO:
        <read-only code>
        END
```

```
P1      IDENT
        BSS     :LC:-:ZERO:
        <read-only code>
        END
```

The FREEZE directive at the end of P1 preserves all the definitions in this package so they can be referenced in packages P2 amd P3. By including the definitions of all the working storage cells in the preserved definitions, these symbols need not be declared as external. Also, it makes "external" arithmetic on these symbols possible in P2 and P3, and it reduces the number of undefined symbols printed at the end of an assembly. Packages P2 and P3 start with the rather peculiar looking BSS in order to set the location counter so that references between the packages will be correct. This is the main purpose of :LC:, it saves the final value of the location counter from the previous package for use by the current package. In order for this scheme to work, all three packages must be loaded at the same location, usually 0 for large re-entrant programs.

Assume ALPHA is a symbol defined in P1. Unless some special action is taken, ALPHA will be output to DDT three times, once at the end of P1, once at the end of P2, and once at the end of P3. To avoid this, all symbol and opcode definitions are marked after they have been output once so that they won't be output again.

4.12 FRGT Do not output a specific symbol

FRGT $s_1, s_2, \ldots$ [comment]

The symbols s_i (which must have been previously defined) are not output to DDT. FRGT is especially useful in situations where symbols have been used im macro expansions or conditional assemblies, and have meaning only at assembly time. When DDT is later used, memory locations are sometimes printed out in terms of these meaningless symbols. It is desirable to be able to keep these symbols from being delivered to DDT, hence the FRGT directive.

4.125 FRGTOP Forget selected opcodes

FRGTOP $s_1, s_2, \ldots$ [comment]

The s_i must be opcodes. The specified opcodes are marked as forgotten and will not be output to DDT. Since DDT knows in advance about the standard instruction set (e.g., LDA, BRS, CIO), FRGTOP or such opcodes has no effect. It follows that the chief use of FRGTOP will be to suppress output of opcodes generated by OPD and POPD.

FRGTOP does not take a label.

4.128 GLOBAL Reverse external specification

GLOBAL [comment]

Causes all symbols which would normally not be external to be external and all symbols which would be external not to be external. This directive remains in effect until an END or LOCAL directive is encountered at which time the normal external determination method is used. For example,

```
        GLOBAL
START   LDA     =1
 A      EXT      B
$C      STB      X
```

would cause START to be external and A and C not to be external.

4.13 IDENT Identification of a package

symbol IDENT [comment]

The symbol in the label field is delivered to DDT as a special identification record. DDT uses the IDENT name in conjunction with its treatment of local symbols: in the event of a name conflict between local symbols in two different subprograms, DDT resolves the ambiguity by allowing the user to concatenate the preceding IDENT name with the symbol in question. Also, during an assembly the first six characters of the symbol followed by the word 'IDENT' are typed on the teletype to show the user what package is being assembled. The progress of an assembly can be followed by placing IDENT's at various points in the package.

4.14 LIST Set listing controls

4.143 LOCAL Restore normal external meaning

LOCAL [comment]

Restores normal external determination method. (See GLOBAL directive.)

4.15 NOLIST Reset listing controls

$\left\{ \begin{array}{l} \text{LIST} \\ \text{NOLIST} \end{array} \right\}$ [s_1, ... [comment]]

There are various booleans which control the format in which statements are listed (certain fields and/or certain kinds of statements may be suppressed, or listed selectively). The user is allowed to set (or reset) these booleans via the LIST (or NOLIST) command. Each of the s_i may be one of the following special symbols:

s_i Set (or reset)	What is (or is not) listed
LCT	the current value of the location counter, in octal
SLCT	the symbolic address of the current value of the location counter
VAL	the value of the statement, if it is one of the directives: EQU, NCHR, NARG, IF, ELSF. (in octal)
SRC	the symbolic source code
COM	the comment field of a statement, a comment statement
CALL	macro and RPT calls
DEF	MACRO and RPT definitions
EXP	macro and RPT expansions
SKIF	the skipped parts of an IF statement
EXT	external symbol references (at the end of the assembly

In addition, s_i may be "ALL", which will cause all of the booleans in the table to be set (or reset).

If a LIST (or NOLIST) directive is encountered for which no arguments (s_i) have been specified, NARP will begin (or cease) listing statements on the LISTING FILE (the teletype, in case no other listing file is specified when the assembly is begun) according to the current settings of the listing booleans. Including "GO" among the arguments for a LIST (or NOLIST) will have the same effect.

When NARP is called, the listing booleans are initialized as follows:

Set: LCT, VAL, SRC, COM, CALL, DEF, EXP, EXT
RESET: SLCT, SKIF

and NARP is in its "no list" state, i.e., listing will not be started unless (and until) the program initiates it with a LIST directive.

Examples of the LIST directive:

```
        NOLIST     ALL        Resets all format booleans
        LIST       SRC, GO    Sets SRC boolean and starts listing.
```

(only the source code will be listed)

Examples of listing format:

```
  LCT      SLCT      VAL               SRC                         COM
 00117    (A)         3     A          EQU        6/2         (SET A)
 00117    (HERE)            HERE       LDA        A*B,2
 00120    (HERE+1)                     CLB
```

4.16 OCT Interpret integers as octal

OCT [comment]

The radix for integers is set to eight so that all following integers (except those with a D-suffix) are interpreted as octal.

4.17 OPD Define an opcode

```
symbol    OPD    value[,class[,shift kludge]]
```

The symbol in the label field is defined as an opcode with a value equal to the first expression in the operand field. All expressions in the operand field must be defined and absolute; if an optional expression does not appear then the value 0 is assumed.

value : computed mod 2^{24} (see important note below)

class : must have a value of 0,1, or 2:

- 0 - the opcode may or may not have an operand
- 1 - the opcode does not take an operand
- 2 - the opcode requires an operand

shift kludge: must have a value of 0 or 1:

- 0 - non-shift instruction (see section 3)
- 1 - shift instruction (see section 3)

Note: Although an opcode that takes operands can be defined with bits b10-b23 set, the user must be careful of what he is doing. In particular, if such an opcode appears in an instruction which contains a literal or an undefined value then bits b10-b23 of the opcode are set to zero.

If the symbol in the label field is already defined as an opcode then the old definition is lost.

Examples:

```
ADD    OPD    055B5,2
CLA    OPD    04600001B,1
RCY    OPD    0662B4,2,1
NOP    OPD    020B5
```

4.18 PAGE Begin a new page on the listing

PAGE [expression [comment]]

This directive causes page ejects on the assembly listing medium. The number of ejects is determined by the expression in the operand field (which must be defined and absolute). If there is no operand then one eject is assumed. If a page eject has just occurred then one less than the specified number of ejects is made.

4.19 POPD Define a programmed operator

symbol   POPD   value[,class[,shift kludge]]

This directive does exactly what OPD does with one addition: The instruction BRU* is placed in the memory location whose address is in b2-b8 of the value given to the symbol (this address must be in the range [100B, 177B]). Thus

```
MIN     POPD    100B5,2
LMIN    SKG*    0           THE CALL 'MIN ALPHA' WILL
        BRR     0           CAUSE THE MINIMUM OF
        LDA*    0           A-REG AND ALPHA TO BE
        BRR     0           LEFT IN A-REG.
```

will cause BRU LMIN to be loaded in word 100B.

4.20 RELORG Assemble relative with absolute origin

RELORG expression [comment]

On occasion it is desirable to assemble in the midst of otherwise normal program a batch of code which, although loaded in core in one position, is destined to run from another position in memory. (It will first be moved there in a block.) This is particularly useful when preparing program overlays. The expression in the operand field (which must be absolute and defined) denotes an origin in memory. The following occurs when the directive is encountered:

a.) The current value of the location counter is saved, and in its place is put the absolute origin (i.e., the value of the expression). This fact is not revealed to DDT, however, so during loading the next instruction assembled will be placed in the next memory cell available as if nothing had happened.

b.) The mode of assembly is switched to absolute, i.e., all symbols defined in terms of the location counter will be absolute.

It is possible to restore normal relocatable assembly (see section 4.22).

As an example of the use of RELORG, consider a program beginning with RELORG 300B. The assembler's output represents an absolute program whose origin is 00300_8, but which can be loaded anywhere using DDT in the usual fashion. Of course, before executing the program it will be necessary to move it to location 00300_8.

As another example, consider the following use of RELORG and RETREL:

```
<normal relocatable program>
RELORG 100B
<absolute program with origin at 100B>
RELORG 200B
<absolute program with origin at 200B>
```

```
RETREL
<normal relocatable program>
RELORG 300B
<absolute program with origin at 300B>
END
```

4.21 REM Type out remark

REM text

This directive causes the text in its operand and comment fields to be typed out either on the teletype or whatever file has been designated as the text file (see section 6.2). This typeout occurs regardless of what listing controls are set. The directive may be used for a variety of purposes: It may inform the user of the progress of assembly; it may give him instructions on what to do next (this might be especially nice for complicated assemblies); it might announce the last date the source language was updated; or it might be used within complex macros to show which argument substrings have been created during expansion of a highly nested macro (for debugging purposes).

4.22 RETREL Return to relocatable assembly

RETREL [comment]

This directive is used when it is desired to return to relocatable assembly after having done a RELORG. It is not necessary to use RETREL unless one desires more relocatable program. An example of the use of RETREL is shown in section 4.20. The effects of RETREL are

a.) to restore the location counter to the value it would have had if the RELORG (s) had never appeared, and

b.) to return the assembly to relocatable mode so that labels are no longer absolute.

4.23 TEXT Generate text (4 character per word)

[[$]label] TEXT string [comment]

This directive is exactly the same as ASC (see section 4.1) except that characters are taken as six bits each and are stored four to a word.

5.0 Conditional assemblies and macros

5.1 IF, ELSF, ELSE, and ENDF   If statements

It is frequently desirable to permit the assembler either to assemble or to skip blocks of statements, depending on the value of an expression at assembly time. This is primarily what is meant by conditional assembly. In NARP, conditional assembly is done by using either an if statement or a repeat statement.

The format of an if statement is

```
IF      expression      [comment]
< if body >
ENDF    [comment]
```

The if body is any block of NARP statements, in particular, it may contain directives of the form

```
ELSF      expression      [comment]
```

and

```
ELSF      [comment]
```

If the operand of IF is true, then the block of code up to the matching ENDF (or ELSF or ELSE) is processed; otherwise, it is skipped. The values for true and false are:

true : value of expression $> \emptyset$

false : value of expression $\leq \emptyset$

Examples:

```
IF      1>Ø
LDA     ALPHA  }  processed
STA     BETA   }
ENDF

IF      Ø
LDA     GAMMA  }  skipped
STA     DELTA  }
ENDF
```

Often there are more than two alternatives, so the ELSF directive is used in the if body. When ELSF is encountered while skipping a block of statements, its operand is evaluated (just as for IF) to decide whether to process the block following the ELSF.

Examples:

```
        IF      Ø > 1
        LDA     ALPHA       skipped
        ELSF    1 > Ø
        LDA     BETA        processed
        ENDF

        IF      Ø > 1
        LDA     ALPHA       skipped
        ELSF    Ø > 1
        LDA     BETA        skipped
        ENDF

        IF      1 > Ø
        LDA     ALPHA       processed
        ELSF    1 > Ø
        LDA     BETA        skipped
        ENDF

        IF      Ø > 1
        LDA     ALPHA       skipped
        ELSF    1 > Ø
        LDA     BETA        processed
        ELSF    1 > Ø
        LDA     GAMMA       skipped
        ENDF
```

From the last two examples above it should be clear that either no blocks are processed or precisely one is; thus, as soon as one block is processed, all following blocks are skipped regardless of whether the ELSF expressions are true.

An ELSE directive is equivalent to an ELSF directive with a true expression.

Example:

```
IF      Ø > 1
LDA     ALPHA       skipped
ELSE
LDA     BETA        processed
ENDF
```

As a more general example, consider the following:

```
IF      e1
< body 1 >
ELSF    e2
< body 2 >
ELSF    e3
< body 3 >
ELSE
< body 4 >
ENDF
```

There are four possibilities:

a) $e1 > \emptyset$: process body 1, skip the other three

b) $e1 \leq \emptyset$, $e2 > \emptyset$: process body 2, skip the other three

c) $e1 \leq \emptyset$, $e2 \leq \emptyset$, $e3 > \emptyset$: process body 3, skip the other three

d) $e1 \leq \emptyset$, $e2 \leq \emptyset$, $e3 \leq \emptyset$: process body 4, skip the other three

The bodies between the IF, ELSF, ELSE, and ENDF directives may contain arbitrary NARP statements, in particular they may contain other if statements. This nesting of if statements may go to any level.

When evaluating the expression in the operand field of IF or ELSF, all undefined symbols are treated as if they were defined with value -1. These expressions must be absolute.

5.2 RPT, CRPT, and ENDR Repeat statements

A repeat statement is a means of processing the same text many times. The format is

```
[[$]label]    RPT    expression[,increment list]      [comment]
              < repeat body >
              ENDR    [comment]
```

The value of the RPT operand (which must be defined and absolute) determines how many times the repeat body will be processed, while the increment list (described below) is a mechanism to allow the values of various symbols to be changed each time the repeat body is processed.

Example:

```
        ABC     RPT     4
                DATA    0
                ENDR
```

This is equivalent to

```
        ABC     DATA    0
                DATA    0
                DATA    0
                DATA    0
```

An increment list has the form (s=e1[,e2])...(s=e1[,e2]) where s stands for a symbol and e1 and e2 denote expressions (which must be absolute; undefined symbols are treated as if they were defined with the value -1). Before the repeat body is processed for the first time, each symbol in the list is given the value of its associated e1. Thereafter, each symbol is incremented by the value of its associated e2 just before the repeat body is processed. If e2 is missing, the value 1 is assumed. There is no limit on the number of elements that may appear in an increment list.

Example:

```
        RPT     3,(I=4)(J=0,-1)
        DATA    I
        DATA    J*I+1
        ENDR
```

This results in code equivalent to the following:

```
        DATA    4
        DATA    0*4+1    =1
        DATA    5
        DATA    -1*5+1   =-4
        DATA    6
        DATA    -2*6+1   =-11
```

There is another format for RPT:

[[$]label]   RPT   (s=e1[,e2],e3)[increment list]   [comment]

In this case, the number of times the repeat body is processed is determined by the construct (s=e1[,e2],e3). This is the same as an increment list except that it includes a third expression (which must be absolute; all undefined symbols are treated as if they were defined with the value -1), namely a bound on the value of the symbol. As soon as the bound is passed, processing of the repeat body stops. In the example above, the same effect could have been achieved by writing the head of the repeat statement as

```
        RPT     (J=0,-1,-2)(I=4)
```

or as

```
        RPT     (I=4,6)(J=0,-1)
```

Note that the bound does not have to be positive or greater than the initial value of the symbol being incremented; the algorithm for determining when the bound has been passed is given below.

Occasionally one wishes to perform an indefinite number of repeats, terminating on an obscure condition determined in the course of the repeat operation. The conditional repeat directive, CRPT, serves this function. Its effect is like that of RPT (and

its repeat body is also closed off with an ENDR) except that instead of giving a number of repeats, its associated expression is evaluated just prior to each processing of the repeat body to determine whether to process the block. As for IF, > 0 means true, ≤ 0 means false; the expression must be defined and absolute each time it is evaluated. The form is

```
[[$]label]    CRPT    expression[,increment list]    [comment]
```

For example, one may write

```
        CRPT    X > Y
```

or

```
        CRPT    STOP,(X=1,2)(Y=-3)
```

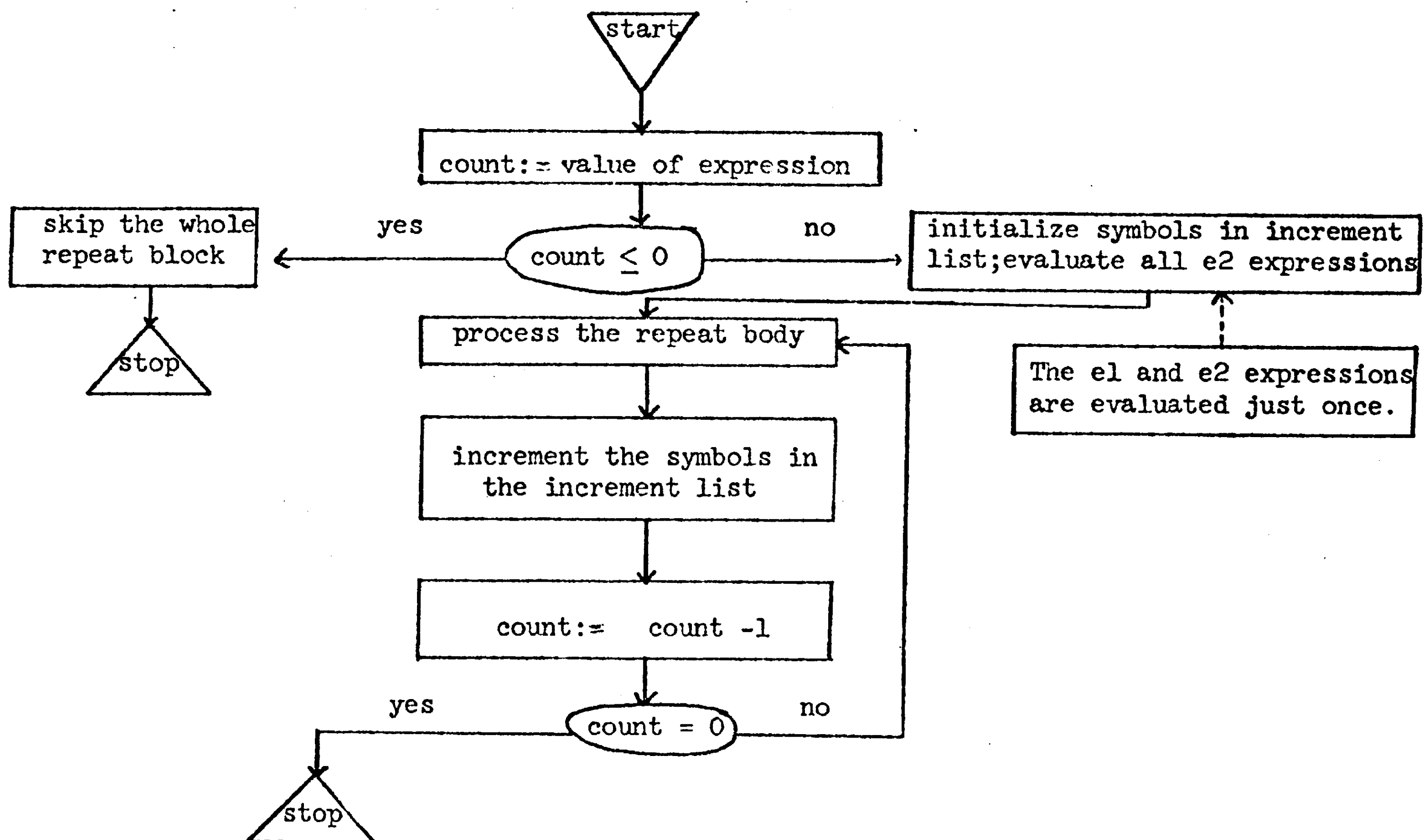
Note that the statement

```
        CRPT    10
```

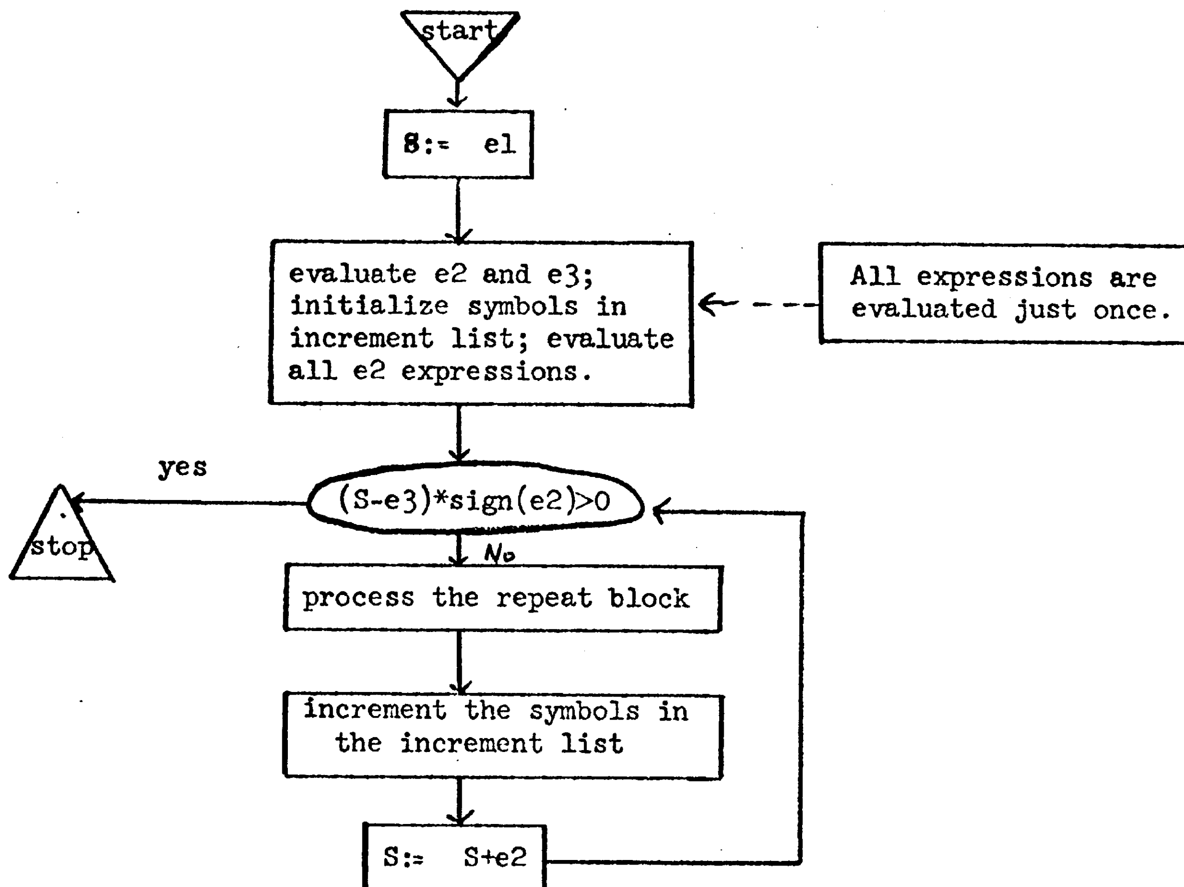
will cause an infinite number of repeats.

The following flowcharts describe precisely the actions of the various repeat options:

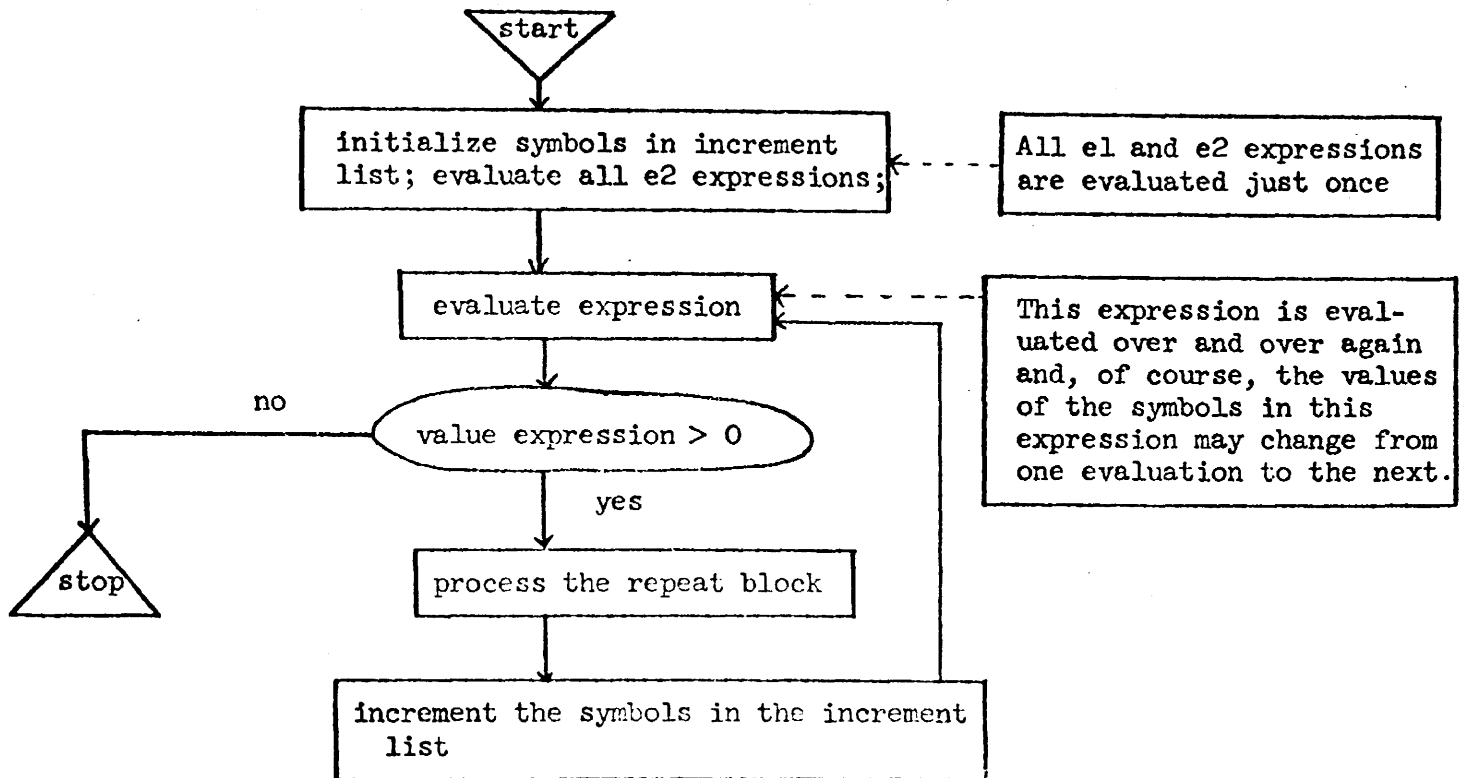
```
        RPT     expression[,increment list]
```



RPT (S=e1[,e2],e3)[increment list]



CRPT expression[,increment list]



The contents of a repeat body may contain any NARP code, in particular it may contain other repeat statements; the nesting of repeat statements may go to any level.

5.3 Introduction to macros

On the simplest level a macro name may be thought of as an abbreviation or shorthand notation for one or more assembly language statements. In this respect it is like an opcode in that an opcode is the name of a machine command and a macro name is the name of a sequence of assembly language statements.

The 940 has an instruction for skipping if the contents of a specified location are negative, but there is no instruction for skipping if the accumulator is negative. The instruction SKA (skip if memory and the accumulator do not compare ones) will serve when used with a cell whose contents mask off all but the sign bit. The meaning of SKA when used with such an operand is "skip if A is positive". Thus a programmer writes

```
        SKA     =4B7
        BRU     NEGCAS          NEGATIVE CASE
```

However, it is more than likely the case that the programmer wants to skip if the accumulator is negative. Then he must write

```
        SKA     =4B7
        BRU     *+2
        BRU     POSCAS          POSITIVE CASE
```

Both of these situations are awkward in terms of assembly language programming.

But we have in effect just developed simple conventions for doing the operations SKAP and SKAN (skip if accumulator positive or negative). Define these operations as macros:

```
SKAP    MACRO
        SKA     =4B7
        ENDM


SKAN    MACRO
        SKA     =4B7
        BRU     *+2
        ENDM
```

Now, more in keeping with the operations he had in mind, the

Programmer may write

```
A22     SKAN
        BRU     POSCAS
```

The advantages of being able to use SKAP and SKAN should be apparent. The amount of code written in the course of a program is reduced; this in itself tends to reduce errors. A greater advantage is that SKAP and SKAN are more indicative of the action that the programmer had in mind, so that programs written in this way tend to be easier to read. Note, incidentally, that a label may be used in conjunction with a macro. Labels used in this way are usually treated like labels on instructions; they are assigned the current value of the location counter. This will be discussed in more detail later.

Before discussing more complicated uses of macros, some additional vocabulary should be established. A macro is an arbitrary sequence of assembly language statements together with a symbolic name. During assembly, the macro is stored in an area of memory called the string storage. Macros are created (or, as is more frequently said, defined) by giving a name and the associated sequence of statements. The name and the beginning of the sequence of statements are designated by the MACRO directive:

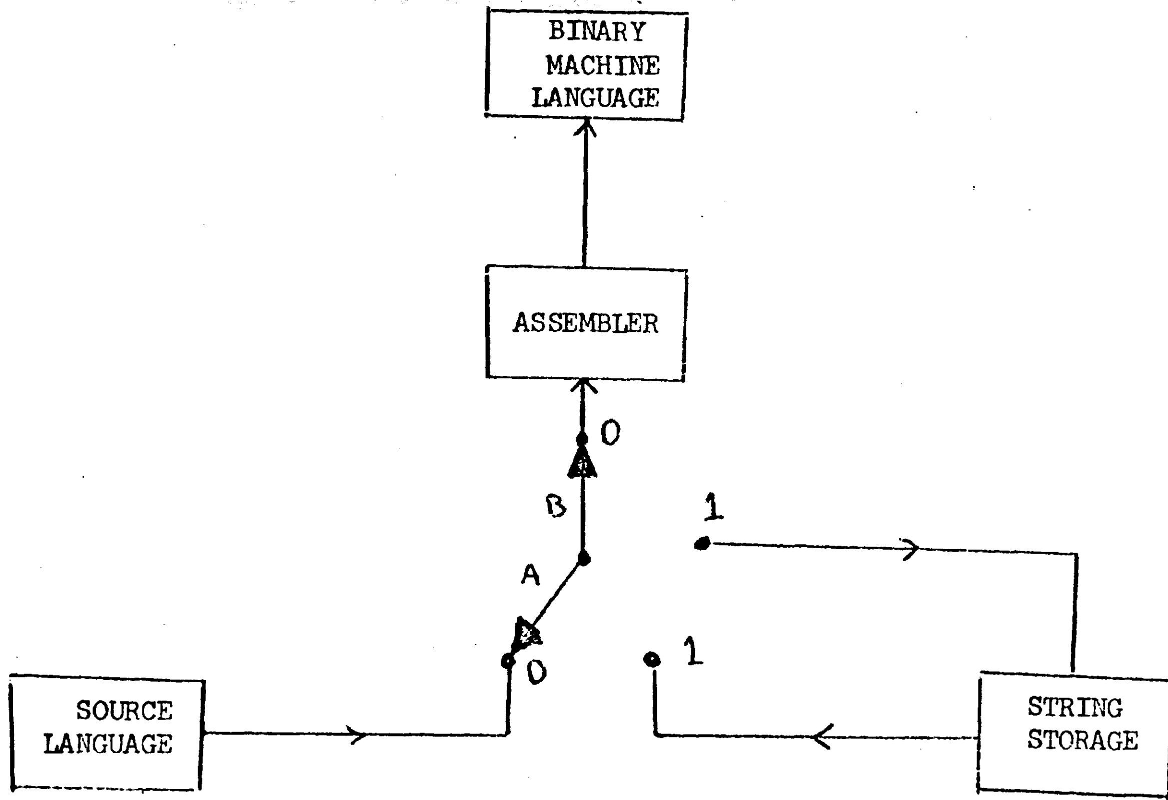
```
name    MACRO
          .
          .
        ENDM
```

The end of the sequence of statements is indicated by the ENDM directive.

Refer to figure 1. When the assembler encounters a MACRO directive, switch B is thrown to position 1 so that the macro is simply copied into the string storage; note that the assembler does no normal processing but simply copies the source language. When the ENDM terminating the macro definition is encountered, switch B is put back to position Ø and the assembler goes on processing as usual.

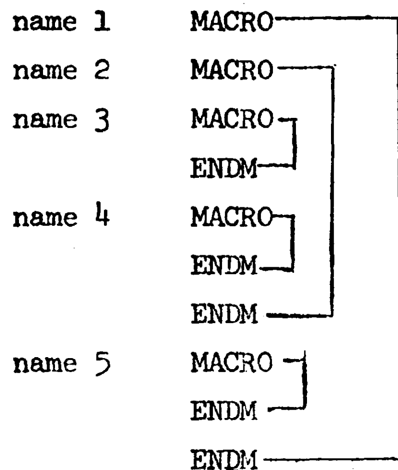
It is possible that within a macro definition other definitions

Figure 1: Information Flow During Macro Processing



A	B	Effect
0	0	normal assembly
0	1	macro definition
1	0	macro expansion
1	1	macro definition during macro expansion

may be embedded. The macro defining machinery counts the occurrences of the MACRO directive and matches them against the occurrences of ENDM. Thus switch B is actually placed back in position 0 only when the ENDM matching the first MACRO is encountered. Therefore, MACRO and ENDM are opening and closing brackets around a segment of source language. Structures like the following are possible:



The utility of this structure will not be discussed here. Use of this feature of imbedded definitions should in fact be kept to a minimum since the implementation of this assembler is such that it uses large amounts of string storage in this case. What is important, however, is an understanding of *when* the various macros are defined. In particular, when name 1 is being defined, name 2, 3, etc., are *not* defined; they are merely copied into string storage. Name2, for example, will not be defined until name1 is expanded. (It should be noted that macros, like opcodes, may be redefined.)

The use of a macro name in the opcode field of a statement is referred to as a *call*. The assembler, upon encountering a macro call, moves switch A to position 1 (see figure 1). Input to the assembler from the original source file temporarily stops and comes instead from string storage. During this period the macro is said to be undergoing *expansion*. It is clear that a macro must be defined before it is called.

An expanding macro may include other macro calls, and these, in turn, may call still others. In fact, macros may even call themselves; this is called *recursion*. Examples of the recursive use of macros are given later. When a new macro expansion begins

within a macro expansion, information about the progress of the current expansion is saved. Successive macro calls cause similar information to be saved. At the end of each expansion the information about each previous expansion is restored. When the final expansion terminates, switch A is placed back in position 0, and input is again taken from the source file.

Now let us carry our example one step further. One might argue that the action of skipping is itself awkward. It might be preferable to write macros BRAP and BRAN (branch to specified location if contents of accumulator are positive or negative). How is one to do this? The location to which the branch should go is not known when the macro is defined, in fact, different locations will be used from call to call. The macro processor, therefore, must enable the programmer to provide some of the information for the macro expansion at call time. This is done by permitting dummy arguments in macro definitions to be replaced by arguments (i.e., arbitrary substrings) supplied at call time. Each dummy argument is referred to in the macro definition by a subscripted symbol. This symbol or dummy name is given in the operand field of the MACRO directive.

Let us define the macro BRAP:

```
BRAP        MACRO       LABEL
            SKAN
            BRU         LABEL(1)
            ENDM
```

When called by the statement 'BRAP POSCAS', the macro will expand to

```
            SKA         =4B7
            BRU         *+2
            BRU         POSCAS
```

Note that BRAP was defined in terms of another macro, SKAN. Also note that as defined BRAP was intended to take only one argument; other macros may use more than one argument.

The macro CBE (compare and branch if equal) takes two arguments. The first argument is the location of a cell to be compared for equality with the accumulator; the second is a branch location in case of equality. The definition is

```
CBE     MACRO   D
        SKE     D(1)
        BRU     *+2
        BRU     D(2)
        ENDM
```

When CBE is called by the statement

```
CBE     =21B,EQLOC
```

the statements generated will be

```
SKE     =21B
BRU     *+2
BRU     EQLOC
```

Note that in the macro call, the arguments are separated by commas.

The following sections describe macro definitions and calls in more detail.

5.4 MACRO, LMACRO, and ENDM   Macro definition

The form of a macro definition is:

```
        ⎧ MACRO  ⎫
name    ⎨   or   ⎬     [dummy[,generated,expression]    [comment]
        ⎩ LMACRO ⎭
```

where name, generated, and dummy are all symbols, and expression is an expression.

LMACRO is completely equivalent to MACRO except that if name is defined as a macro with MACRO the construct

label name arguments

will automatically cause "label" to be defined as the current value of the location counter, whereas if name were defined with LMACRO this automatic definition of "label" would not occur.

Some details of the definition

If generated appears, it should not be the same symbol as dummy, and neither of them should be "MACRO", "LMACRO", or "ENDM."

If name is already defined as an opcode, the old definition is completely replaced by the new.

If the MACRO (or LMACRO) directive has no operand, then name is defined as an opcode that takes no operands. Otherwise, name becomes an opcode that may or may not take an operand.

Whole-line comments (lines beginning with *) in the macro body are not saved in string storage as part of the macro definition, but comments following instructions are. Thus, it behooves the programmer to avoid the latter, as they eat up string storage.

When a macro body is placed in string storage, superfluous blanks are removed. Thus, any contiguous string of blanks is compressed to one blank with the following exceptions:

a) Blanks enclosed in single quotes (') are not compressed.

b) Blanks enclosed in double quotes (") are not compressed.

c) Blanks enclosed in parentheses are not compressed. In this use, the nesting of parentheses is taken into account, but a parenthesis between single or double quotes is not considered as part of the nesting structure.

In most cases the programmer need not worry about these conventions, although there are times when he may get pinched. For example, if

```
ASC     %A␢␢␢B%
```

appears in a macro definition, it will be expanded as

```
ASC     %A␢B%
```

To avoid such problems use

```
ASC     'A␢␢␢B'
```

5.4.1 Dummy arguments

The dummy argument specified as an operand of the MACRO directive may appear anywhere in the macro body, followed by a subscript. At call time the subscript is evaluated and its value is used to select the appropriate argument supplied in the call. Before describing the various kinds of dummy arguments a few conventions are needed:

a) In the following, "argument" will refer to the character string as given in the macro call after possible enclosing parentheses have been removed (see section 5.6 for the format of argument strings).

b) The number of arguments supplied by the call is n ($n \geq 0$).

c) The number of characters in argument ei is n(ei).

d) The structure ei for i an integer stands for an expression. (However, its value stands for some argument usually, so ei will be used somewhat ambiguously to stand for an expression or the value of an expression.) The first argument in a call is numbered 1.

e) The dummy argument is assumed to be "D".

With the above in mind, we consider the three forms of dummy arguments:

1) D(e1)

This expands to argument e1 (which may be the null string), where $0 \leq e1 \leq n$. (If e1 = 0 then D(e1) expands to the label field of the macro call; see section 5.6.)

Special notation: D() = D(1)

2) D(e1,e2)

If e1 > e2 then this expands to the null string (range of values of e1 and e2 is arbitrary), otherwise, this expands to argument e1 through e2, where $0 \leq e1 \leq e2 \leq n$, with each argument enclosed in parentheses and a comma inserted between each argument. For example, D(3,3) = (D(3)).

Special notation: D(,) = D(1,n)

D(,e1) = D(1,e1)

D(e1,) = D(e1,n)

3) D(e1$e2,e3)

In all cases, $0 \leq e1 \leq n$ must be true. If $e2 > e3$ then this expands to the null string (range of values of e2 and e3 is arbitrary), otherwise, it expands to characters e2 through e3 of argument e1, counting the first character of an argument as character 1. If either e2 or e3 lies outside the argument, then the nearest boundary is chosen. To be more precise, before using e2 and e3 to select the piece of argument e1 that is desired, the following transformation is made:

e2:= max (1,e2); e3:= max (1,e3);
e2:= min (n(e1), e2); e3:= min (n(e1),e3);

If argument e1 is the null string, then the dummy argument expands to the null string regardless of the values of e2 and e3.
Special notations:

D(e1$,) = D(e1$1, n(e1)) = D(e1)
D(e1$,e2) = D(e1$1,e2)
D(e1$e2,) = D(e1$e2,n(e1))
D(e1$e2) = D(e1$e2,e2)
D(e1$) = D(e1$1) = D(e1$1,1)

In any of the six forms mentioned above, e1 may be missing; if so, 1 is assumed. E.g., D($) = D(1$1,1).
A general rule which will help in remembering what the special notations mean is the following: "Whenever an expression is missing from a form, the value 1 is assumed unless the expression is missing from a place where an upper bound is expected (as in D(3,) or D(3$2,), in which case the largest 'reasonable' value is assumed."

In any of the above three cases, if an expression which designates an argument is out of range, then an error message is typed and argument 0 is taken.

Following is an example of the various forms of dummy arguments:

Macro definition:

```
XAMPLE      MACRO     D
            D(2)      D()         D(0)
            ASC       'D(2,4)'
            TEXT      'D(4,)'     D(-3,-4)      NULL STRING
            ASC       'D(1$3,4)'
            ASC       'D(2$-3,18)'
            ENDM
```

Macro call:

```
BETA        XAMPLE    ALPHA,ADD,GAMMA,DELTA
```

Macro expansion:

```
BETA        ADD       ALPHA         BETA
            ASC       '(GAMMA),(DELTA)'
            TEXT      '(DELTA)'     NULL STRING
            ASC       'PH'
            ASC       'ADD'
```

5.4.2 Generated symbols

A macro should not, of course, have in its definition an instruction having a label. Successive calls of the macro would produce a multiply-defined symbol. Sometimes, however, it is convenient to put a label on an instruction within a macro. There are at least two ways of doing this. The first involves transmitting the label as a macro argument when it is called. This is most reasonable in many cases; it is in fact often desirable so that the programmer can control the label being defined and can refer to it elsewhere in the program.

However, situations do arise in which the label is used purely for reasons local to the macro and will not be referred to elsewhere. In cases like this it is desirable to allow for the automatic creation of labels so that the programmer is freed from worrying about this task. This may be done by means of the generated symbol.

A generated symbol name may be declared when a macro is defined, specifying the name and the maximum number of generated symbols which will be encountered during an expansion. These two items follow the dummy symbol name given in the MACRO directive (as shown in section 5.4 above) if the programmer wishes to use generated symbols in a macro. For example,

```
MUMBLE      MACRO    D,G,4
            < macro body >
            ENDM
```

might contain references to G(1), G(2), G(3), and G(4), these being individual generated symbols.

With regard to generated symbols the macro expansion machinery operates in the following fashion: A generated symbol base value for each macro is initialized to zero at the beginning of assembly. As each generated symbol is encountered, the expression constituting its subscript is evaluated. This value is added to the base value, and the sum is produced as a string of digits concatenated to the generated symbol name; the first digit is always 0 to reduce the likelihood of the generated symbol being identical to

a normal symbol defined elsewhere by the programmer. Thus, the first time MUMBLE is called, G(2) will be expanded as GØ2, G(4) as GØ4, etc.

At the end of a macro expansion, the generated symbol base value is incremented by the amount designated by the expression following the generated symbol name in the MACRO directive. This is 4 in the case of MUMBLE. Thus, the second call of MUMBLE will produce in place of G(2), GØ6, the third call will produce GØ1Ø, etc. It should be clear that the generated symbol name should be kept as short as possible.

The expression in the macro head (call it m) must have a value in the range [1,1023]. A generated symbol subscript must have a value in the range [1,m].

5.4.3 Concatenation

Occasionally, it is desirable to have a dummy argument follow immediately after an alphanumeric character, for example, to have D(1) follow just after ALPHA. But then the assembler would not recognize the dummy because it would see ALPHAD(1) instead of D(1). To get around this problem the concatenation symbol '.&' is introduced. Its sole purpose is to separate a dummy argument (or conceivably a generated symbol) from a preceding alphanumeric character during macro definition. Thus, the example becomes ALPHA.&D(1). The concatenation symbol is not stored in string storage so it does not appear during expansion.

As an example, say that we wish to define a macro STORE, and suppose we have established the convention that certain temporary storage cells begin with the letters A, B, or X depending on what register is saved there. The definition is:

```
STORE       MACRO     D
            ST.&D($)      D(1)
            ENDM
```

If called by the statements

```
            STORE     B17
            STORE     X44
```

the macro will expand as

```
            STB       B17
            STX       X44
```

The concatenation symbol may appear anywhere in a macro definition, but it is only necessary in the case described above. If one macro is defined within another, any concatenation symbols within the inner macro will not be removed during the definition of the enclosing macro.

5.4.4 Conversion of a value to a digit string

As an adjunct to the automatic generation of symbols (or for any other purposes for which it may be suited) a capability is provided in the assembler's macro expansion machinery for conversion of the value of an expression at call time to a string of decimal digits. The construct

```
($expression)
```

will be replaced by a string of digits equal to the value of the expression. For example, if X=5 then

```
AB($2*X+1)
```

will be transformed into

```
AB11
```

If the value of the expression is zero then the digit string is '0'; if it is negative then the digit string is preceded by a minus sign.

This conversion scheme can also be used inside repeat blocks; for example

```
         RPT      (I=1,10)
TEMP($I) BSS       1
         ENDR
```

creates 10 cells labelled TEMP1 through TEMP10.

5.4.5 A note on subscripts

The expressions used as subscripts for dummy arguments and generated symbols, as well as the expressions used in the conversion to a digit string must be absolute. Any undefined symbols appearing in these expressions are treated as if they were defined with the value -1. These expressions may themselves contain dummy arguments, generated symbols, and ($...), so constructs like ($4+D(I*D(3))) are possible.

5.5 NARG and NCHR Number of arguments and number of characters

Macros are more useful if the number of arguments supplied at call time is not fixed. The precise meaning of a macro (and indeed, the result of its expansion) may depend on the number or arrangement of its arguments. In order to permit this, the macro undergoing expansion must be able to determine at call time the number of arguments supplied. The NARG directive makes this possible.

NARG functions like EQU except that no expression is used with it. Its form is

```
        [$]symbol     NARG     [comment]
```

The function of the directive is to equate the value of the symbol to the number of arguments supplied to the macro currently undergoing expansion. The symbol can then be used by itself or in expressions for any purpose. NARG may appear in any macro, even one which has no dummy argument (and thus never has any arguments at call time); it is an error for NARG to appear outside a macro.

It is also useful to be able to determine at call time the number of characters in an argument. NCHR functions by equating the symbol in its label field to the number of characters in its operand field. Its form is

```
        [$]symbol     NCHR     [character string     [comment]]
```

where "character string" has exactly the same form as an argument supplied for a macro call, i.e., if it involves blanks, commas, or semi-colons it should be enclosed in parentheses (see section 5.6). NCHR can appear anywhere, both inside and outside macros, but it is most useful in macros for determining the length of arguments.

Examples:

```
    A     NCHR     ABCDEF                A:=6
    B     NCHR     (,,XYZ,,)             B:=7
    C     NCHR     D(I)                  C:=?
```

5.6 Macro calls

The format of a macro call is:

```
[[$]label]      macroname      [argstring]      [comment]
```

Such a call causes the macro whose name appears in the opcode field to be expanded, with the dummy arguments in the macro body replaced by the actual arguments of the argstring.

The label field is always transmitted as argument 0, so that D(el),where el has value 0, is always legal inside a macro. An occurrence of D(el), where el=0, will be replaced by the label field. If the label field is empty, then D(el) expands to the null string. At most seven characters will be transmitted this way: the first six characters of the symbol in the label field, preceded by '$' if the label field begins with '$'.

If the user wishes to transmit an argument to a macro in the label field of the macro call, but does not wish to have the symbol in this field defined, he should define the macro with LMACRO rather than MACRO. (See section 5.4) An example:

```
NT      LMACRO    D
        RPT       D(1)
        DATA      D(2)
        ENDR
D(0)    DATA      -D(1)
        ENDM
```

when called by:

```
DTE     NT        4,4B7
```

expands as:

```
        DATA      4B7
        DATA      4B7
        DATA      4B7
        DATA      4B7
DTE     DATA      -4
```

Notice that this would have caused a doubly-defined symbol error had MACRO been used rather than LMACRO.

A macro call may or may not have an arg string (see section 5.4). If an arg string is present, it may contain any number of arguments, in fact, more than are referred to by the macro.

Before describing an arg string, the following should be noted: blanks, commas, semi-colons, and parentheses that are enclosed in single or double quotes are treated exactly like ordinary characters enclosed in quotes; they do not serve as terminators, separators, delimiters, or the like. In effect, when the argument collector in NARP is collecting arguments for a macro call, the occurrence of a quote causes it to stop looking for special characters except for a matching quote (and, of course, carriage return, which is an absolute terminator). A single quote enclosed in double quotes is not a special character and vice versa. Thus, when a blank, comma, semi-colon, or parenthesis is referred to in the following, it is understood that it is *not* enclosed in quotes.

An arg string for a macro call has the following format:

<arg>,<arg>,...,<arg> <terminator>

where a terminator is a blank, semi-colon, or carriage return. There are three forms of <arg>:

1. <arg> may be the null string.
2. If the first character of <arg> is *not* a left parenthesis then <arg> is a string of characters not containing blank, comma, semi-colon, or carriage return (remember that blanks, commas, and semi-colons may appear in <arg> if they are enclosed in quotes).
3. If the first character of <arg> *is* a left parenthesis the <arg> does not terminate until a blank, comma, or semi-colon is encountered *after* the right parenthesis which matches the initial left parenthesis ("matches" means that all left and right parentheses in the argument are noted and paired off with each other so that a nested parentheses structure is possible).
   Of course, a carriage return at any point immediately

terminates <arg>. Again, remember that blanks, commas, semi-colons, and parentheses enclosed in quotes are ignored when <arg> is being delimited. The initial left parenthesis and its matching right parenthesis (which need not be the last character in <arg>) are removed before <arg> is transmitted to the macro. Examples:

```
AMAC        (,␣;␣,),,'HOUSE,␣ROGER',(AB")")
   D(1) =   ,␣;␣,
   D(2) =   null string
   D(3) =   'HOUSE,␣ROGER'
   D(4) =   AB")"
```

5.7 Examples of conditional assembly and macros

1. It is desired to have a pair of macros SAVE and RESTOR for saving and restoring active registers at the beginning and end of subroutines. These macros should take a variable number of arguments so that, for example, one can write

```
SAVE      A,SUBRS
RESTOR    A,B,X,SUBRS
```

to generate the code

```
STA       SUBRSA
LDA       SUBRSA
LDB       SUBRSB
LDX       SUBRSX
```

To this end we first define a macro MOVE which is called by the same arguments delivered to SAVE and RESTOR, but with the string 'ST' or 'LD' appended.

```
MOVE      MACRO        D
X         NARG
          RPT          (Y=2,X-1)
          D(1)D(Y)     D(X)D(Y)
          ENDR
          ENDM
```

Now SAVE and RESTOR can be defined as

```
SAVE      MACRO        D
          MOVE         ST,D(,)
          ENDM
```

```
RESTOR    MACRO     D
          MOVE      LD,D(,)
          ENDM
```

2. Many programmers use flags, memory cells that are used as binary indicators. The instruction SKN (skip if memory negative) makes it easy to test these flags if the convention is used that a flag is set (true) if it contains -1 and reset (false) if it contains Ø. We want to define two macros, SET and RESET to manipulate these flags; furthermore, it is desirable to deliver at call time the name of an active register which will be used for the action. Calls of the macros will look like

```
SET       A,FLG1,FLG2,FLG3
RESET     X,FLG37,FLG12
```

As in the previous example we make use of an intermediate macro, STORE, which takes the same arguments as SET and RESET.

```
STORE     MACRO     D
X         NARG
          RPT       (Y=2,X)
          ST.&D(1)  D(Y)
          ENDR
          ENDM
```

Now SET and RESET are defined as

```
SET       MACRO     D
          LD.&D(1)  =-1
          STORE     D(,)
          ENDM

RESET     MACRO     D
          CL.&D(1)
          STORE     D(,)
          ENDM
```

3. The following macro, MOVE, takes any number of pairs of arguments; the first argument of each pair is moved to the second, but an argument may itself be a pair of arguments, which may themselves be pairs of arguments, etc. MOVE extracts pairs of argument structures and transmits them to a second macro MOVE1.

```
MOVE      MACRO     D
X         NARG
          RPT       (Y=1,2,X)
          MOVE1     D(Y),D(Y+1)
          ENDR
          ENDM
```

The main work is done in MOVE1 which calls itself recursively until it comes up with a single pair of arguments.

```
        MOVE1     MACRO      D,G,2
        G(1)      NARG
        G(2)      EQU        Ø
                  IF         G(1)=2
                  LDA        D(1)
                  STA        D(2)
                  ELSE
                  RPT        G(1)/2,(G(2)=G(2)+1)
                  MOVE1      D(G(2)),D(G(2)+G(1)/2)
                  ENDR
                  ENDF
                  ENDM
```

When MOVE is called by

```
                  MOVE       A,B
```

the code generated is

```
                  LDA        A
                  STA        B
```

When called by

```
                  MOVE       A,B,C,D
```

the code generated is

```
                  LDA        A
                  STA        B
                  LDA        C
                  STA        D
```

When called by

```
                  MOVE       (A,B),(C,D)
```

the code generated is

```
                  LDA        A
                  STA        C
                  LDA        B
                  STA        D
```

And when called by

```
        MOVE      ((A,B),(C,D)),((E,F),(G,H))
```

the code generated is

```
        LDA       A
        STA       E
        LDA       B
        STA       F
        LDA       C
        STA       G
        LDA       D
        STA       H
```

It is instructive to trace the last example by hand to see how the recursive calls of MOVE1 work. This is an exercise left to the reader.

6.0 Operating NARP

6.1 Starting an assembly

Assuming that the user has entered the time-sharing system, NARP is called by hitting the ESCAPE button until the EXEC answers (by typing '-') and then typing 'NARP' followed by a carriage return. Control is then turned over to NARP and a source file must be specified; other information may also be supplied, if desired. The general format is:

		default convention
-NARP.		
SOURCE FILE:	file name	none
OBJECT FILE:	file name	none
TEXT FILE:	file name	TELETYPE

All three files do not have to be specified.

The various options are discussed in more detail below:

SOURCE FILE: As soon as NARP is started this line is typed and the user must specify a file containing the programs to be assembled. When he terminates the name with a carriage return, NARP responds with 'OBJECT FILE:' on the next line.

When the name is terminated with a line feed, no further requests are made. The assembly begins immediately and produces no object file or Teletype listing except for error messages. This feature is primarily used to FREEZE symbols and macros into the symbol table.

OBJECT FILE: The file name given specifies where the binary output from the program should go. If the file name is terminated by a line feed, then NARP waits for a text file to be specified.

TEXT FILE: The file name given specifies where the listing of the source program and of the error messages should go.

6.2 Multiple program assembly

The source file may contain more than one program, each terminated by an END directive. Each program is assembled separately with each binary being appended to the object files. Multiple program object files can be loaded in DDT with no addition and in FOS with the addition of a FIILIB directive.

6.3 Assembly of multiple files

After completing a NARP assembly of one file it is possible to run a second NARP assembly which uses definitions made in the first. All those definitions preceding the FREEZE directive will be retained. This process may be repeated. Using this feature, it is possible to break up symbolic programs which are too large for QED to handle into manageable segments. To assemble a second or subsequent file, use the CONTINUE command of the EXECutive in place of the NARP command.

Appendix A: List of all pre-defined opcodes and pre-defined symbols

NARP in its original form contained no symbol definitions except that for "OPD". An initialization run was performed using the definitions given below. The NARP subsystem as available to the DIAL-DATA user is an initialized version. That is, the opcodes and symbols shown below are already defined, and the user does not make an initialization run.

The following table is a listing of an initialization program used to initialize the opcode table and symbol table of NARP. It will be noted that in some cases the OPD directive has four operands instead of the usual three; the fourth operand specifies the type (directive, macro, or instruction) of the opcode being defined. It is only possible to use four operands for OPD when NARP is being initialized, and once the initialization program has been assembled, OPD will only accept three operands.

```
CAX     OPD     04600400B,1      COPY A INTO X
XXA     OPD     04600600B,1      EXCHANGE X AND A
CBX     OPD     04600020B,1      COPY B INTO X
CXB     OPD     04600040B,1      COPY X INTO B
XXB     OPD     04600060B,1      EXCHANGE X AND B
STE     OPD     04600122B,1      STORE EXPONENT
LDE     OPD     04600140B,1      LOAD EXPONENT
XEE     OPD     04600160B,1      EXCHANGE EXPONENTS
CNA     OPD     04601000B,1      COPY NEGATIVE OF A INTO A
AXC     OPD     04600401B,1      COPY A TO X, CLEAR A

BRU     OPD     00100000B,2      BRANCH UNCONDITIONALLY
BRX     OPD     04100000B,2      INCREMENT INDEX AND BRANCH
BRM     OPD     04300000B,2      MARK PLACE AND BRANCH
BRR     OPD     05100000B,2      RETURN BRANCH
BRI     OPD     01100000B,2      BRANCH AND RETURN FROM INTERRUPT

SKS     OPD     04000000B,2      SKIP IF SIGNAL NOT SET
SKE     OPD     05000000B,2      SKIP IF A EQUALS M
SKG     OPD     07300000B,2      SKIP IF A GREATER THAN M
SKR     OPD     06000000B,2      REDUCE M, SKIP IF NEGATIVE
SKM     OPD     07000000B,2      SKIP IF A EQUALS M ON B MASK
SKN     OPD     05300000B,2      SKIP IF M NEGATIVE
SKA     OPD     07200000B,2      SKIP IF M AND A DO NOT COMPARE ONES
SKB     OPD     05200000B,2      SKIP IF M AND B DO NOT COMPARE ONES
SKD     OPD     07400000B,2      DIFFERENCE EXPONENTS AND SKIP

RSH     OPD     06600000B,2,1    RIGHT SHIFT AB
RCY     OPD     06620000B,2,1    RIGHT CYCLE AB
LRSH    OPD     06624000B,2,1    LOGICAL RIGHT SHIFT AB
LSH     OPD     06700000B,2,1    LEFT SHIFT AB
LCY     OPD     06720000B,2,1    LEFT CYCLE AB
NOD     OPD     06710000B,2,1    NORMALIZE AND DECREMENT X

HLT     OPD     00000000B,0      HALT
ZRO     OPD     00000000B,0      ZERO
NOP     OPD     02000000B,0      NO OPERATION
EXU     OPD     02300000B,2      EXECUTE

BPT1    OPD     04020400B,1      BREAKPOINT TEST 1
BPT2    OPD     04020200B,1      BREAKPOINT TEST 2
BPT3    OPD     04020100B,1      BREAKPOINT TEST 3
BPT4    OPD     04020040B,1      BREAKPOINT TEST 4

ROV     OPD     02200001B,1      RESET OVERFLOW
REO     OPD     02200010B,1      RECORD EXPONENT OVERFLOW
OVT     OPD     02200101B,1      OVERFLOW TEST AND RESET
OTO     OPD     02200100B,1      OVERFLOW TEST ONLY

EIR     OPD     00220002B,1      ENABLE INTERRUPTS
DIR     OPD     00220004B,1      DISABLE INTERRUPTS
AIR     OPD     00220020B,1      ARM/DISARM INTERRUPTS
IET     OPD     04020002B,1      INTERRUPT ENABLED TEST
IDT     OPD     04020004B,1      INTERRUPT DISABLED TEST
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ALCW    OPD     00250000B,1     ALERT CHANNEL W
DISW    OPD     00200000B,1     DISCONNECT CHANNEL W
ASCW    OPD     00212000B,1     ALERT TO STORE ADDRESS IN CHANNEL W
TOPW    OPD     00214000B,1     TERMINATE OUTPUT ON CHANNEL W

CATW    OPD     04014000B,1     CHANNEL ACTIVE TEST
CETW    OPD     04011000B,1     CHANNEL W ERROR TEST
CZTW    OPD     04012000B,1     CHANNEL W COUNT TEST
CITW    OPD     04010000B,1     CHANNEL W INTER-RECORD TEST

EOD     OPD     00600000B,2     ENERGIZE OUTPUT D
MIW     OPD     01200000B,2     M INTO W BUFFER WHEN EMPTY
WIM     OPD     03200000B,2     W BUFFER INTO M WHEN FULL
PIN     OPD     03300000B,2     PARALLEL INPUT
POT     OPD     01300000B,2     PARALLEL OUTPUT
EOM     OPD     00200000B,2     ENERGIZE OUTPUT M
BETW    OPD     04020010B,1     W BUFFER ERROR TEST
BRTW    OPD     04021000B,1     W BUFFER READY TEST

TSN     OPD     00222000B,1     NORMAL TO MONITOR MODE
CKN     OPD     00220100B,1     CLOCK ON
CKF     OPD     00220200B,1     CLOCK OFF
LRR1    OPD     00220400B,1     LOAD RELABELLING REGISTER 1
LRR2    OPD     00221000B,1     LOAD RELABELLING REGISTER 2
LRR3    OPD     00221400B,1     LOAD RELABELLING REGISTER 3

BIO     OPD     57600000B,2     BLOCK I/O
BRS     OPD     57300000B,2     BRANCH TO SYSTEM
CIO     OPD     56100000B,2     CHARACTER I/O
CIT     OPD     53400000B,2     CHARACTER INPUT AND TEST
CTRL    OPD     57200000B,2     CONTROL
DBI     OPD     54200000B,2     DRUM BLOCK INPUT
DBO     OPD     54300000B,2     DRUM BLOCK OUTPUT
DWI     OPD     54400000B,2     DRUM WORD INPUT
DWO     OPD     54500000B,2     DRUM WORD OUTPUT
EXS     OPD     55200000B,2     EXECUTE INSTRUCTION IN SYSTEM MODE
EXSYM   OPD     51500000B,2     EXS RELOCATED FROM SYMS IN MONITOR
FAD     OPD     55600000B,2     FLOATING ADD
FDV     OPD     55300000B,2     FLOATING DIVIDE
FFAD    OPD     52600000B,2     FLOATING ADD WITH FA
FFADD   OPD     52000000B,2     FLOATING ADD,X DOUBLED
FFDI    OPD     53100000B,2     FLOATING DIVIDE INVERTED WITH FA
FFDID   OPD     51400000B,2     FLOATING DIVIDE INVERTED,X DOUBLED
FFDV    OPD     53000000B,2     FLOATING DIVIDE WITH FA
FFDVD   OPD     52200000B,2     FLOATING DIVIDE,X DOUBLED
FFMP    OPD     52700000B,2     FLOATING MULTIPLY WITH FA
FFMPD   OPD     52100000B,2     FLOATING MULTIPLY,X DOUBLED
FFSB    OPD     53200000B,2     FLOATING SUBTRACT WITH FA
FFSBD   OPD     52300000B,2     FLOATING SUBTRACT,X DOUBLED
FFSI    OPD     53300000B,2     FLOATING SUBTRACT INVERTED WITH FA
FFSID   OPD     51300000B,2     FLOATING SUBTRACT INVERTED,X DOUBLED
FMP     OPD     55400000B,2     FLOATING MULTIPLY
FSB     OPD     55500000B,2     FLOATING SUBTRACT
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GCD     OPD     53700000B,2     GET CHARACTER AND DECREMENT
GCI     OPD     56500000B,2     GET CHARACTER AND INCREMENT
ISC     OPD     54000000B,2     INTERNAL TO STRING CONV(FLOATING OUTPUT)
IST     OPD     55000000B,2     INPUT FROM SPECIFIED TELETYPE
LAS     OPD     54600000B,2     LOAD FROM SECONDARY MEMORY
LDP     OPD     56600000B,2     LOAD POINTER (AB)
LDFM    OPD     52400000B,2     LOAD FLOATING ACCUMULATOR
LDFMD   OPD     51600000B,2     LOAD FLOATING ACCUMULATOR,X DOUBLED
OST     OPD     55100000B,2     OUTPUT TO SPECIFIED TELETYPE
SAS     OPD     54700000B,2     STORE IN SECONDARY MEMORY
SBRM    OPD     57000000B,2     SYSTEM BRM
SBRR    OPD     05140000B,2     SYSTEM BRR
SIC     OPD     54100000B,2     STRING TO INTERNAL CONV(FLOATING INPUT)
SKSE    OPD     56300000B,2     SKIP IF STRINGS EQUAL
SKSG    OPD     56200000B,2     SKIP IF STRING GREATER
STFM    OPD     52500000B,2     STORE FLOATING ACCUMULATOR
STFMD   OPD     51700000B,2     STORE FLOATING ACCUMULATOR,X DOUBLED
STI     OPD     53600000B,2     SIMULATE TELETYPE INPUT
STP     OPD     56700000B,2     STORE POINTER (AB)
TCI     OPD     57400000B,2     TELETYPE CHARACTER INPUT
TCO     OPD     57500000B,2     TELETYPE CHARACTER OUTPUT
WCD     OPD     53500000B,2     WRITE CHARACTER AND DECREMENT
WCH     OPD     56400000B,2     WRITE CHARACTER
WCI     OPD     55700000B,2     WRITE CHARACTER AND INCREMENT
WIO     OPD     56000000B,2     WORD I/O


* DIRECTIVE DEFINITIONS:

ASC     OPD     0,2,0,1         ASCII STRING
BES     OPD     1,2,0,1         BLOCK END SYMBOL
BSS     OPD     2,2,0,1         BLOCK START SYMBOL
COPY    OPD     3,2,0,1         REGISTER CHANGE
CRPT    OPD     4,2,0,1         CONDITIONAL REPEAT
DATA    OPD     5,2,0,1         DATA WORD
FIILIB  OPD     6,1,0,1         FORTRAN II LIBRARY
DEC     OPD     7,1,0,1         SET NUMBER RADIX TO 10
DELSYM  OPD     8,1,0,1         DELETE SYMBOL
ELSE    OPD     9,1,0,1         ELSE
ELSF    OPD     10,2,0,1        ELSE IF
END     OPD     11,1,0,1        END OF PROGRAM
ENDF    OPD     12,1,0,1        END IF
ENDM    OPD     13,1,0,1        END MACRO
ENDR    OPD     14,1,0,1        END REPEAT
EQU     OPD     15,2,0,1        EQUATE
EXT     OPD     16,0,0,1        EXTERNAL
FREEZE  OPD     17,1,0,1        FREEZE TABLES
FRGT    OPD     18,2,0,1        FORGET SYMBOL
IDENT   OPD     19,1,0,1        IDENTIFICATION SYMBOL
IF      OPD     20,2,0,1        IF
LIST    OPD     21,0,0,1        TURN ON LISTING
MACRO   OPD     22,0,0,1        MACRO DEFINITION
NARG    OPD     23,1,0,1        NUMBER OF ARGUMENTS
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NCHR    OPD     24,Ø,Ø,1          NUMBER OF CHARACTERS
LOCCNT  OPD     25,2,Ø,1          LOCATION COUNTER
NOLIST  OPD     26,Ø,Ø,1          TURN OFF LISTING
OCT     OPD     27,1,Ø,1          SET NUMBER RADIX TO 8
POPD    OPD     28,2,Ø,1          POP DEFINITION
RELORG  OPD     29,2,Ø,1          RELATIVE ORIGIN
RETREL  OPD     30,1,Ø,1          RETRIEVE ORIGIN
RPT     OPD     31,2,Ø,1          REPEAT
TEXT    OPD     32,2,Ø,1          STRING (FOUR CHARACTERS PER WORD)
LMACRO  OPD     33,Ø,Ø,1          ALTERNATIVE MACRO DEF'N
GLOBAL  OPD     34,1,Ø,1          SET GLOBAL MODE
REM     OPD     35,2,Ø,1          PRINT REMARK ON TEXT FILE
LOCAL   OPD     36,1,Ø,1          SET LOCAL MODE
FRGTOP  OPD     37,2,Ø,1          FORGET SELECTED OPCODES
CSECT   OPD     38,2,Ø,1          CONTROL SECTION
NBSS    OPD     39,2,Ø,1          NONCOMMUNICATIVE BSS

:ZERO:  EQU     *
:LC:    EQU     :ZERO:
        FRGT    :ZERO:,:LC:

        FREEZE

        END                       LAST LINE OF NARP INITIALIZATION PROGR
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