LA-5285-MS

INFORMAL REPORT

See Attached Errata Sheet

C.3

Recommended Use of SI Units in the Nuclear Rocket Engine Program

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scientific laboratory
of the University of California
LOS ALAMOS, NEW MEXICO 87544

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OFFICE MEMORANDUM

TO : Holders of LA-5285-MS

DATE: July 13, 1973

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FROM : C. I. Mitchell, ISD-6

SUBJECT : ERRATUM

SYMBOL : TI-73-301

Title page (i).

Change date in statement reading "This report originally issued as N-4-3044, February 1972." to December 1972.

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Recommended Use of SI Units in the Nuclear Rocket Engine Program

by

R. J. Bohl

This report originally issued as N-4-3044, ~~February~~ December 1972.

CONTENTS

I. ABSTRACT

This document contains basic technical information for the use of the international system of units (SI) that has been adopted recently for reporting all Nuclear Rocket Engine Program technical work. Special problems are discussed and some modifications to the SI system are introduced, which are dictated by the special needs of the Nuclear Rocket Engine Program. Some background of the SI system and the considerations that led to its adoption for the Nuclear Rocket Engine Program are also reviewed.

II. INTRODUCTION

An Act of Congress in 1866 declared that "It shall be lawful throughout the United States of America to employ the weights and measures of the metric system"; and the international prototype metre and kilogram have been fundamental standards in the U.S.A. since 1893, from which the customary units, the yard and the pound, were derived.

However, only recently has the National Bureau of Standards been authorized by Public Law 90-472, called the "Metric Study Act of 1968", to investigate all aspects of changing from customary units in the U.S.A. to SI units. Since then the National Aeronautics and Space Administration* (NASA) has issued a directive to utilize the SI system within its organization. The Small Nuclear Rocket Engine (SNRE) program conducted by the Los Alamos Scientific Laboratory (LASL) adopted the use of SI units (with certain exceptions) in 1972; and most recently David S. Gabriel, Manager, Space Nuclear Systems Division, directed J. P. Jewett, Chief, Space Nuclear Systems Office - Nevada (SNSO-N), to extend the conversion to SI units to all activities at the Nuclear Rocket Development Station (NRDS). (A copy of this letter is included in Appendix I.)

The present document, which should serve as a guide to the use of SI units in the Nuclear Rocket Engine Program, is based on the Metric Practice Guide,[1] E 380-72, published by the American Society of Testing and Materials (ASTM), in June, 1972.

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*A copy of the NASA Policy Directive on the use of metric units is included in Appendix I for informational and historical purposes.

III. SUMMARY

The Metric Practice Guide, E 280-72, is accepted as the primary metrication authority, but minor modifications of E 380-72 were made that were dictated by the special needs of the Nuclear Rocket Engine Program. These modifications are not necessarily in contradiction to or inconsistent with E 380-72. For example:

- For angular measurements the use of both the radian and the arc degree plus the use of decimal submultiples of the arc degree is permitted.

- All digits both to the left and to the right of the decimal point should be written without either a comma or a space.

- Only the preferred prefixes are to be used.

- For rotational velocity the use of both revolutions per second and radians per second is acceptable.

- An energy unit, the electron volt (eV), will continue to be used. Few recommendations exist, in either E 380-72 or in this document, concerning units in the field of radiation or radiation effects. The recommendations of the International Commission on Radiological Units and Measurements (ICRU) should be used until definite recommendations are forthcoming for the SI system.

- Engineering drawings will be dimensioned with U.S. Customary Units.

- A reactivity unit, the dollar, will be used, because the dollar is an internationally accepted unit and there is no discussion or recommendation in E 380-72.

IV. DEFINITIONS AND TERMINOLOGY

United States Customary Units are still in common use within the United States. However, it is becoming increasingly more difficult for the U.S.A. to achieve agreement in international dealings with countries that predominately use the metric system because the SI system is being almost universally adopted abroad. Besides, it may be economically prudent for the U.S.A. to abandon the U.S. Customary Units in favor of the SI system.

The name *Le Systême International d'Unitês* is officially abbreviated SI in all languages.

One advantage of the SI system is its coherence.[1] A system of units is coherent if the product or the quotient of any two unit quantities in the system is a unit of the resulting quantity.[1] Unit system coherence greatly simplifies calculations.

Two words that often appear are metricize and metrication. To metricize is to convert any other unit to its metric equivalent, whereas metrication is defined as an act tending to increase the use of the metric system.

Common definitions of terms that will be helpful to ensure consistently reliable conversion and rounding practices are listed in Appendix II. A good understanding of Appendix II is imperative.

V. UNIT NAMES AND SYMBOLS

In all system of units, whether coherent or incoherent, the magnitudes of some physical quantities must be selected arbitrarily and declared to have unit value.[1] These magnitudes form a set of standards and are called base units. The SI system contains seven base units and two supplementary units. These units are:

TABLE I. BASE AND SUPPLEMENTARY UNITS

Base Units

Quantity	Unit	SI Symbol
length	metre	m
mass	kilogram	kg
time	second	s
thermodynamic temperature	kelvin	K
electric current	ampere	A
luminous intensity	candela[a]	cd
amount of substance	mole	mol
Supplementary Units		
plane angle	radian	rad
solid angle	steradian	sr

[a] The e in candela is pronounced as a long ē.

The SI base units for length and mass have two different spellings each. In the past the most prevalent spellings in the U. S. A. were meter and kilogram, whereas in Europe the spellings metre and kilogramme are now in common use. Recently the National Bureau of Standards has issued a brochure and compromised by using the spellings metre and kilogram. These spellings will therefore be used in this document, even though these spellings have not yet been universally adopted.[2]

Any combination of base units can be denoted as a derived unit. Therefore, theoretically, the number of derived units is unlimited. The SI system presently contains 15 derived units that have special names; it is likely that more will be named in the future.

Derived units, both named and unnamed, are listed in Table II, together with their equivalents expressed in combinations of derived and base units (in column called "Formula") as well as strictly in base units.

TABLE II. DERIVED UNITS

Quanity	Unit	SI Symbol	Formula	Base
acceleration	metre per second squared	...	m/s^2	$m \cdot s^{-2}$
activity (of a radio-active source)	distintegration per second	...	(disintegration)/s	s^{-1}
angular acceleration	radian per second squared	...	rad/s^2	$rad \cdot s^{-2}$
angular velocity	radian per second	...	rad/s	$rad \cdot s^{-1}$
area	square metre	...	m^2	m^2
density	kilogram per cubic metre	...	kg/m^3	$m^{-3} \cdot kg$
electric capacitance	farad	F	A·s/V	$m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^2$
electrical conductance	siemens	S	A/V	$m^{-2} \cdot kg^{-1} \cdot s^3 . A^2$
electric field strength	volt per metre	...	V/m	$m \cdot kg \cdot s^{-3} \cdot A^{-1}$
electric inductance	henry	H	V·s/A	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-2}$
electric potential difference	volt	V	W/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
electric resistance	ohm	Ω	V/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$
electromotive force	volt	V	W/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
energy	joule	J	N·m	$m^2 \cdot kg \cdot s^{-2}$
entropy	joule per kelvin	...	J/K	$m^2 \cdot kg \cdot s^{-2} \cdot K^{-1}$
force	newton	N	$kg \cdot m/s^2$	$m \cdot kg \cdot s^{-2}$
frequency	hertz	Hz	(cycle)/s	s^{-1}
illuminance	lux	lx	lm/m^2	$m^{-2} \cdot cd \cdot sr$
luminance	candela per square metre	...	cd/m^2	$m^{-2} \cdot cd$
luminous flux	lumen	lm	cd·sr	cd·sr
magnetic field strength	ampere per metre	...	A/m	$m^{-1} \cdot A$
magnetic flux	weber	Wb	V·s	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$
magnetic flux density	tesla	T	Wb/m^2	$kg \cdot s^{-2} \cdot A^{-1}$
magnetomotive force (ampere-turn)	ampere	A	...	A
power	watt	W	J/s	$m^2 \cdot kg \cdot s^{-3}$
pressure	pascal	Pa	N/m^2	$m^{-1} \cdot kg \cdot s^{-2}$
quanity of electricity	coulomb	C	A·s	s·A
quantity of heat	joule	J	N·m	$m^2 \cdot kg \cdot s^{-2}$
radiant intensity	watt per steradian	...	W/sr	$m^2 \cdot kg \cdot s^{-3} \cdot sr^{-1}$

TABLE II (continued)

Quanity	Unit	SI Symbol	Formula	Base
specific heat	joule per kilogram-kelvin	...	$J/kg \cdot K$	$m^2 \cdot s^{-2} \cdot K^{-1}$
stress	pascal	Pa	N/m^2	$m^{-1} \cdot kg \cdot s^{-2}$
thermal conductivity	watt per metre-kelvin	...	$W/m \cdot K$	$m \cdot kg \cdot s^{-3} \cdot K^{-}$
velocity	metre per second	...	m/s	$m \cdot s^{-1}$
viscosity, dynamic	pascal-second	...	$Pa \cdot s$	$m^{-1} \cdot kg \cdot s^{-1}$
viscosity, kinematic	square metre per second	...	m^2/s	$m^2 \cdot s^{-1}$
voltage	volt	V	W/A	$m^2 \cdot kg \cdot s^{-3} \cdot A$
volume	cubic metre	...	m^3	m^3
wavenumber	reciprocal metre	...	(wave)/m	m^{-1}
work	joule	J	$N \cdot m$	$m^2 \cdot kg \cdot s^{-2}$

VI. SI PREFIX SERIES

An important feature of any system of units is the number size. However, it is difficult (if not impossible) to define a system of units and to maintain convenient number sizes for all fields of science and engineering. Prefixes were therefore adopted in the SI system to maintain reasonable number sizes. These prefixes are listed in Table III. Those prefixes representing 10 raised to a power of 3 or a multiple thereof are called preferred prefixes. The prefixes hecto (100), deka (10), deci (0.1), and centi (0.01) are to be avoided,[3] although the use of the prefix centi is solidly entrenched and is likely to continue for some time. Only the preferred prefixes are to be used in Nuclear Rocket Engine Program technical work.

TABLE III. SI PREFIXES

Factor	Prefix	Symbol	Factor	Prefix	Symbol
10^{12}	tera (tĕr′ȧ)	T	10^{-1}	deci (dĕs′ĭ)	d
10^{9}	giga (jĭ′gȧ)	G	10^{-2}	centi (sĕn′tĭ)	c
10^{6}	mega (mĕg′ȧ)	M	10^{-3}	milli (mĭl′ĭ)	m
10^{3}	kilo (kĭl′ō)	k	10^{-6}	micro (mī′krō)	μ
10^{2}	hecto (hĕk′tō)	h	10^{-9}	nano (năn′ō)	n
10^{1}	deka (dĕk′ȧ)	da	10^{-12}	pico (pē′kō)	p
			10^{-15}	femto (fĕm′tō)	f
			10^{-18}	atto (ăt′tō)	a

VII. RECOMMENDATIONS FOR WRITING SI SYMBOLS

Any unit named for a person is spelled in lower case, but its symbol is always capitalized. For example, force is measured in newtons, N. Unit names may be plural, but unit symbols are never pluralized. Periods should not be used after SI unit symbols except at the end of a sentence. A unit value is separated from its symbols by a space.

Either a solidus (oblique stroke, /), or a negative power, or a horizontal line are acceptable to indicate unit divisions.[4] The solidus is not to be repeated on the same line. All units to the left of a solidus are in the numerator, whereas all to the right are in the denominator. The use of the sign • (center dot) to indicate a product of units is optional. If the center dot is not used, the units may be written either with or without a space. The signs ÷ and x are not accepted to indicate unit division and multiplication, respectively.

The use of multiple, compound, or hyphenated prefixes is positively prohibited. A prefix and a unit should not be separated by a center dot or by a space. Prefixes will not be used in the denominator, with one exception, the kilogram (kg), because the kilogram is a base unit in the SI system. A power superscript modifies the whole symbol, including the prefix [i.e., μm^2 means $(\mu m)^2$].

Special examples of writing symbols are presented in Table IV. The symbols for gigagram and specific heat are included to illustrate the proper use of a prefix with the mass unit and the only accepted use of a prefix in the denominator, respectively.

TABLE IV. SYMBOL WRITING TECHNIQUES

	Acceptable	Prohibited
Voltage	V	v
	$m^2 \cdot kg/s^3 \cdot A$	$m^2 \cdot kg/s^3/A$
	$m^2 \cdot kg/(s^3 \cdot A)$	$m^2 \cdot kg/(sec^3 \cdot A)$
	$m^2 kg\ s^{-3}\ A^{-1}$	$m^2 kg\ s^{-3}/A$
	$\frac{m^2\ kg}{s^3 A}$	$\frac{m^2 g}{mA\ s^3}$
	MV	kkV
	MW/A	W/μA
	MWA^{-1}	mega-WA^{-1}
	$MW \cdot A^{-1}$	$M \cdot W \cdot A^{-1}$
	$\frac{MW}{A}$	$\frac{M\ W}{A}$
Gigagram (10^6 kg)	Gg	Mkg
Specific heat	J/kgK	J/kK·g

There are two symbols that are used for both a prefix and a unit of measurement: T and m. The symbol T stands for the prefix tera (10^{12}) and the unit tesla; whereas the m stands for the unit metre and the prefix milli (10^{-3}). Keep in mind that some confusion may result if the center dot is not used judiciously. For instance, mN is a millinewton, whereas m•N is a metre newton (i.e., a joule). Another way to reduce confusion is to write the length unit last, that is, mN for millinewton and Nm for newton metre.

In some countries a comma rather than a period (as in the U.S.A.) is used as a decimal sign, whereas in the U.S.A. the comma has been used to separate numbers at three-digit intervals. To avoid confusion all digits, both to the left and to the right of the decimal point should be written without either a comma or a space in the Nuclear Rocket Engine Program. This is an exception because in E 380-72 it is recommended that a space separate numbers at three-digit intervals.

In the literature exponents of 10 are expressed in various ways; for example: 354000. = 3.54×10^5 = 3.54E+05. The use of E has been accepted for the FORTRAN computer language although none of the various techniques has been approved for the SI system. Indicating exponents of 10 with an E is acceptable for publications and in computer listings.

VIII. UNITS OF IMPORTANCE TO THE NUCLEAR ROCKET ENGINE

Several units of importance to the Nuclear Rocket Engine Program require special mention. These units are discussed individually below.

A. Pressure and Mechanical Stress Units

The units of pressure and stress are pascals. A pascal (Pa) is equal to a newton per square metre (N/m^2). When referring to pressures and stresses the pascal should be used exclusively, and neither N/m^2 nor N/cm^2 are acceptable.

Persons presently using U. S. Customary Units are accustomed to referring to pressures as absolute pressure (psia), gage pressure (psig), and a pressure difference (psid). A metrication expert* believes that practicality should prevail: when practical, use the symbol for absolute pressure and add absolute, gage, or difference in parenthesis, e.g., 500 kPa (abs), if necessary. This practice should be adopted in the Nuclear Rocket Engine Program, but with special emphasis on the words practical and necessary.

The use of the pascal does not result in convenient number sizes for the pressure levels required in testing of present-day reactors at the Nuclear Rocket Development Station (NRDS). Much more reasonable number sizes result when kilopascals (kPa) or, if more appropriate, megapascals (MPa) are used. It is recommended that the control-room displays and the systems from which LASL receives data use kilopascals (kPa) as the pressure unit. NRDS computer listings** or Sanborn charts are allowed to deviate from preferred labeling. However, reports should adhere to the proper use of symbols and writing techniques.

B. Temperature Units

Temperature units are fairly well understood. Note, however, that the unit of temperature is the kelvin (K) and not the *degree* kelvin (°K). For instance, one should refer to 1000 K as one thousand kelvins and not one thousand degrees kelvin.

It is permissible to use degree Celsius (symbol °C) in nonscientific areas.*** The Celsius scale was formally called the centigrade scale and is related directly to the kelvin scale as follows: K = 273.15 + °C, exactly.

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*G. Corry McDonald of Sandia Laboratory, personal communication.

**Only three characters are available to indicate pressure units, and the computer prints only capital letters. The symbol KPA has been suggested for computer listings to indicate absolute pressure in kilopascals. Four digits to the left of the decimal are available to indicate pressure values, and the computer listing will therefore switch to megapascals for pressures greater than 9999.0 kPa.

***A group of thermodynamics experts has suggested a temperature scale called Georgian. Thermometers with the Georgian scale have been manufactured.[5] In the Georgian system the equation of state of a perfect gas is PV=T. This means that the universal gas constant is set equal to unity and temperature is expressed in joules per mole. The freezing point of water is then[5] 2271.16 J/mol. However, it will be many years before the SI base unit of temperature is replaced by the Georgian scale, even if the latter proves to be better.

C. Reactivity Units

At present no reactivity units have been accepted for the SI system. An international committee in which the British are represented is working on the problem. An enquiry at the British Embassy disclosed that the committee is still in an organizational state and that no official recommendations have yet been made. In the U.S.A., the dollar (symbol \$, e.g., 5.0 \$) is commonly used as a unit of reactivity. The Embassy advised to continue to use dollars, with the implication that the British will negotiate acceptance of the dollar unit in the SI system. The use of cents should be discontinued and replaced by the use of preferred prefixes with the dollar, if necessary.

D. Ionizing Radiation Units

The consultative Committee for the Standards of Measurement of Ionizing Radiations (C.C.E.M.R.I.) was set up in 1958.[4] This committee* makes recommendations to the General Conference of Weights and Measures (CGPM), but no official CGPM recommendations concerning ionizing units exist at the time of writing.

The U. S. Customary Unit for absorbed radiation dose is the rad (symbol rad or rd), equal to 10^{-2} J/kg. Expressing radiation dose in J/kg appears to cause only minor problems; the four prefixes M, k, m, and μ would certainly be used, depending upon the application. Dose rates are often quoted in terms of hours (rd/h), where 1 rd/h ≈ 2.78 μW/kg. Dose-rate units of W/kg are fairly practical when used in conjunction with a prefix. Units of J/kg and W/kg should be used in the Nuclear Rocket Engine Program to denote radiation doses and dose rates, respectively.

The activity of an ionization source in U. S. Customary Units is measured in curies (Ci), where 1 Ci = 3.7×10^{10} disintegrations per second. It has been suggested, but not accepted, that activity be expressed in units of hertz, i.e., 1 Ci = 37 GHz. (An American proposal has been made to name 10^6 disintegrations per second a *rutherford*, but there is some doubt[6] that the proposal will be accepted.)

*Since 1969 the CCEMRI has consisted of four sections[4]: Section I, measurements of x and γ rays; Section II, measurements of radionuclides; Section III, Newton measurements; Section IV, α - energy standards.

The 12th CGPM recognized that the unit of activity in the SI system is the s^{-1} and accepted that the curie be retained outside the SI system because the Ci had been used for a long time in many countries.

E. Angular Measure Units

The accepted SI unit for angular measure is the radian (rad). For angular measurements the use of both the radian and the arc degree plus the use of decimal submultiples of the arc degree is permitted in the Nuclear Rocket Engine Program, but the use of the arc minute and arc second is not permitted. Solid angles should be expressed in steradians.

F. Frequency and Angular Velocity Units

In the SI system the unit of frequency is the hertz (Hz) and angular velocity is expressed in rad/s. The input frequency of sinusoidal perturbation experiments should be quoted in hertz as has been done in the past. This is mainly due to the fact that most signal generators are calibrated in hertz, and persons performing these experiments are generally most conversant in frequency units of hertz.

Angular velocity (rad/s) is difficult to visualize and should only be used for convenience sake. It will be used more readily by the theoretician than by the experimentalist. If misinterpretation is possible, any confusion is to be avoided by mathematically relating hertz and rad/s.

Revolution, as related to rotation, is a practical unit whose concept is easy to understand. Shaft speeds are often measured in revolutions per minute (rpm). This practice should be avoided, because the minute is not the basic SI unit of time. The use of revolutions per second is considered by many to be reasonable, but is not recommended by the SI system. The use of revolutions (rev), of revolutions per second (rev/s), and of radians per second is acceptable in the Nuclear Rocket Engine Program.

G. Specific Impulse

The ratio of thrust (N) to flow rate (kg/s) is used in rocket-vehicle trajectory calculations. This ratio has units of velocity (m/s) and is often called effective exhaust velocity (V_e). This ratio is sometimes equated to the product of acceleration due to gravity at the Earth's surface and of a parameter called specific impulse (I_{sp}). By this definition I_{sp} has units of seconds. The unit I_{sp} (in seconds) has been used for many years. It is questionable whether I_{sp} (in seconds) will survive the transition to SI units. The effective exhaust velocity, V_e, expressed in units of m/s, will probably prevail.

H. Length Units

The base unit of length is the metre. The metre should be used with any preferred prefix in accordance with Section VI. The use of the non-preferred prefixes (hecto, deka, deci, and centi) is not permitted for Nuclear Rocket Engine Program work. A micrometre (μm) replaces the micron.[7]

I. Mass and Force Units

The SI mass and force units are the kilogram (kg) and the newton (N), respectively. The mass and force concepts must be clearly understood, and are not to be confused as was so easily done in the U. S. Customary Units system due to the use of the same name (pounds mass and pounds force). The use of kilogram force in the SI system can cause confusion and should be avoided, lest one of the advantages of the SI system be negated.

The c.g.s.-system force unit, the dyne, is not accepted and is replaced by the newton.

Note that for mass, the prefixes apply to gram and not to kilogram: as shown in Table IV, Gg is acceptable, whereas Mkg is not.

J. Energy and Work Units

A unit of energy in common use throughout the world is the electron volt (eV). This unit was devised because the joule is too unwieldy ($1 \text{ eV} = 1.602\ 10 \times 10^{-19}$ J) to be used in certain fields dealing with atomic and subatomic energy levels, e.g., in atomic, nuclear, neutron, and radiation physics. The electron volt will be retained in such contexts. In those few instances, however, where there is an overlap between those fields in which electron volts and joules are used, or where the choice between electron volts and joules is not clear-cut, only joules should be used.

The energy units erg and calorie are not acceptable and are replaced by joules.

K. Time Units

The SI unit for time is the second (see Table I). The second should be used when technical calculations or work are involved; the symbol for second is s, not sec. In cases associated with daily activities, e.g., manpower planning, the use of hours, days, weeks, months, and years is permitted.

IX. ENGINEERING DRAWINGS

Space Nuclear Systems (SNS) decided to retain for the time being the use of U. S. Customary Units on engineering drawings.[8] The use of Customary Units is supposed to alleviate the current problems of procuring items whose drawings and specifications are in a system of units unfamiliar to the suppliers.

It is acceptable, but not necessary, to dimension engineering drawings in both U. S. Customary and SI units.

When the transition to SI units is made, items will be drawn and specified exclusively in SI units, with little effort expended to revise existing drawings.

X. OTHER AREAS OF IMPORTANCE

A. Conversion and Rounding of Numbers

Section 4 of E 380-72 discusses rules for conversion and the rounding of numbers. It is recommended that the reader familiarize himself with these rules. Because Section 4 is very detailed and well-written, no attempt was made to summarize these rules.

B. Acronyms

Tabulated in Appendix III are acronyms that appear often in fields related to units or engineering standards. The list of acronyms is incomplete but is of sufficient size for persons just beginning to familiarize themselves with these fields.

ACKNOWLEDGEMENTS

This document is the result of a joint effort of N-Division, NRTO, and SNSO-N personnel whose contributions are gratefully acknowledged.

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2. Metrologia Editorial Staff, "Nomenclature for Units in Scientific Manuscripts", National Research Council Division of Physics, May 1972, pp 2.

3. D. R. Blackman, "SI Units in Engineering", Macmillan, Melbourne, Australia, 1969, pp 11.

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6. M. Danloux - Dumensnils, "The Metric System", translated by A. Garett, and J. S. Rowlinson, The Athlone Press, London, England, 1969, pp 132.

7. E. A. Mechtly, "The International System of Units", NASA SP-7012, 1969, pp 12.

8. Space Nuclear Systems, "Project Guideline Letter No. 2", May 19, 1972, pp 4.

9. D. V. De Simone, Director U. S. Metric Study, "U. S. Metric Study Interim Report Engineering Standards", NBS SP 345-11, July 1971, pp 12-13.

10. Ad Hoc Committee on Metric Practice, "ASTM Metric Practice Guide", U. S. Department of Commerce, NBS, Handbook 102, March 1967, pp 2.

APPENDIX I

POLICY DIRECTIVE

USE OF THE INTERNATIONAL SYSTEM OF UNITS (SI) IN NASA PUBLICATIONS

NPD 2220.4

September 14, 1970
Effective date

SUBJECT: USE OF THE INTERNATIONAL SYSTEM OF UNITS (SI) IN NASA PUBLICATIONS

REF : NMI 2220.1

1. PURPOSE

To establish NASA policy with respect to the use of the International System of Units (SI) in certain NASA scientific and technical publications. (SI units, physical constants, conversion factors and other information are set forth in NASA SP-7012, "The International System of Units," revised 1969.)

2. APPLICABILITY

This Directive is applicable to NASA Headquarters and field installations. The Jet Propulsion Laboratory is considered a field installation for the purpose of this Directive.

3. BACKGROUND

The internationally approved form of the metric system is generally referred to as SI, (Système International d'Unités). SI units have been adopted by over 100 countries, including every industrial country in the world, except Australia, New Zealand, Canada, and the United States. Australia, New Zealand, and Canada are considering conversion to SI units. In August 1968, Congress enacted Public Law 90-472 which authorizes the Secretary of Commerce to appraise the desirability and practicability of increasing the use of metric units in the United States. In support of this study, NASA has examined some of its own scientific and technical publications and has found that a large percentage of these now use metric or SI units.

4. POLICY

a. Measurement values employed in the NASA scientific and technical publications cited in paragraph 5a shall be expressed in the International System of Units (SI).

b. Expression in both SI units and customary units is acceptable where the use of SI units alone would obviously impair communication or reduce the usefulness of the report to the primary recipients. When both systems of units are used, SI units are to be stated first and customary units afterwards, in parentheses. In each such case, the publication shall state which system of units was used for the principal measurements and calculations.

5. SCOPE AND TIMING

a. Except as set forth in subparagraphs (b) through (d), the provisions of paragraph 4 apply to the following NASA scientific and technical publications as defined in NMI 2220.1:

(1) Technical Reports (NASA TR series)
(2) Technical Notes (NASA TN series)
(3) Technical Memoranda (NASA TM series)
(4) Contractor Reports (NASA CR series)
(5) Special Publications (NASA SP series)

b. All publications set forth in subparagraph (a) which are scheduled for publication sixty days or more following the effective date of this Directive shall comply with the policy of paragraph 4, except that if the official-in-charge of a Headquarters Office, the Director of a field installation, or their respective designees determines such a publication to be in a stage of preparation such that undue expense or time delay would result from compliance, he may waive the requirement.

c. Contractor Reports (NASA CR series) are excepted from the requirements of paragraph 4 if the contract is advertised for bid, in negotiation, or in effect within sixty days of the effective date of this Directive.

d. Contractor Reports (NASA CR series) or Special Publications (NASA SP series) may also be excepted from the requirements of paragraph 4 by determination of the official-in-charge of a Headquarters Office or the Director of a field installation, if in his judgment, use of SI units would impair the usefulness of the report or result in excessive cost. The fact that the provisions of this Directive have been waived under the authority of this subparagraph shall be stated in the preface or otherwise displayed in the report.

George M Low
Deputy Administrator

OCT 2 7 1972

J. P. Jewett, Chief
SNSO-Nevada

CONVERSION TO SI UNITS AT NRDS

LASL is currently conducting the design analysis and reporting of their efforts for the Small Nuclear Rocket Engine in the System of International Units (SI). The purpose of this memorandum is to extend the conversion to SI Units to all activities of NRDS and to inform you that LASL will also be converting all of their activities to SI Units.

I recognize that conversion to SI Units is not without its difficulties and complexities and cannot be instantaneously accomplished. Therefore, you may find it necessary to phase the conversion. Immediate attention should be paid to the conversion of Test Cell C such that its associated data recording and reduction facilities and equipment are converted to SI Units, to the extent that all console readouts, data plots and printouts and test reports are expressed in SI Units, prior to the conduct of NF-2 testing.

Of course, practicality will require certain exceptions such as: (a) drawings and specifications for use by off-site contractors who have not demonstrated their familiarity with the SI Units should be converted to customary units, and (b) reports generated by SNSO-N and their contractors for use outside of NRDS may use customary units as well as SI Units in accordance with the intent and requirements of Paragraph 4(b) of NASA Policy Directive 2220.4.

I suggest that you negotiate a memorandum of understanding or similar written agreement with LASL to define the full scope of the work efforts required to convert to SI Units for the NF-2 testing and establish the basic responsibilities of both organizations.

Original signed by:
David S. Gabriel

David S. Gabriel
Manager

cc: R. Spence, LASL

APPENDIX II
TERMINOLOGY

To help ensure consistently reliable conversion and rounding practices, a clear understanding of the related nontechnical terms is a prerequisite. Accordingly, certain terms are defined as follows:

Accuracy (as distinguished from precision) - The degree of conformity of a measured or calculated value to some recognized standard or specified value. This concept involves the systematic error of an operation, which is seldom negligible.

Approximate - A value that is nearly but not exactly correct or accurate.

Deviation - Variations from a specified dimension or design requirement, usually defining upper and lower limits. (See also tolerance.)

Digit - One of the Ten Arabic numerals (0 to 9) by which all numbers are expressed.

Dimension - A geometric element in a design, such as length, angle, etc., or the magnitude of such a quantity.

Feature - An individual characteristic of a part, such as screw-thread, taper, slot, etc.

Figure (numerical) - An arithmetic value expressed by one or more digits.

Nominal - A value assigned for the purpose of convenient designation; existing in name only.

Precision (as distinguished from accuracy) - The degree of mutual agreement between individual measurements, namely repeatability and reproducibility.

Significant (as applied to a digit) - Any digit that is necessary to define a value or quantity.

Tolerance - The total range of variation (usually bilateral) permitted for a size, position, or other required quantity; the upper and lower limits between which a dimension must be held.

U.S. Customary Units - Units based upon the yard and the pound commonly used in the United States of America and defined by the National Bureau of Standards. Some of these units have the same name as similar units in the United Kingdom (British, English, or U.K. units) but are not necessarily equal to them.

Other terms that may be encountered in the literature dealing with the modernized metric system are defined as follows:

Metricize - To convert any other unit to its metric equivalent. This may be an exact, a rounded, or a rationalized equivalent.

Rationalize - To round completely a converted value to a popular standard figure compatible with noncritical mating components, interchangeable parts, or other nominal sizes in a series.

Engineering Practice - A way in which things are made or done technically, such as in characterizing, constructing, describing, designing, dimensioning, drawing, inspecting, manufacturing, measuring, prescribing, sampling, servicing, testing, or using a product, or a thing made to have prescribed attributes.

Engineering Standard - An engineering practice established by authority or mutual agreement and described in a document to assure dimensional compatibility, quality of product, uniformity of evaluation procedures, or uniformity of engineering language. Examples are documents prescribing screw thread dimensions, chemical composition and mechanical properties of steel, dress sizes, safety standards for motor vehicles, method of test for sulfur in oil, and codes for highway signs.

Measurement Standard - A device or physical phenomenon which is used to define or determine some characteristic of a thing in terms of a unit of measurement established by authority. Examples are gage blocks, weights, thermometers, and mean solar day.

International System of Units (SI) - The coherent system of units based upon and including the metre (length), kilogram (mass), second (time), kelvin (temperature), ampere (electric current), and candela (luminous intensity) as established by the General Conference on Weights and Measures in 1960 under the Treaty of the Meter. In addition the amount of substance (mole) was adopted in 1971. The radian (plane angle) and the steradian (solid angle) are supplementary units of the system. All other units are derived from these nine units.

Customary Units of Measurement - The units most commonly used in trade within a country. In metric countries, they are the units in use prior to the adoption of the International System of Units. In the United States, they are units related to the yard and pound but are frequently referred to as the "inch-pound-system".

Metrication - Any act tending to increase the use of the metric system (SI), whether it be increased use of metric units or of engineering standards that are based on such units.

The definitions listed in Appendix II were obtained from references 1, 9 and 10.

APPENDIX III

ACRONYMS IN COMMON USE

Acronym	Description
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
BIPM	International Bureau of Weights and Measures
CCDM	Consultative Committee for the Definition of the Metre
CCDS	Consultative Committee for the Definition of the Second
CCE	Consultative Committee for Electricity
CCEMRI	Consultative Committee for the Standards of Measurement of Ionizing Radiations
CCP	Consultative Committee for Photometry
CCT	Consultative Committee for Thermometry
CCU	Consultative Committee for Units
CEE	International Commission on Rules for the Approval of Electrical Equipment
CENEL	Committee for the Coordination of European Standards
CGPM	General Conference of Weights and Measures
CIPM	International Committee of Weights and Measures
COPANT	Pan American Standards Commission
ECE	Economic Commission for Europe
IATM	International Association for Testing Materials
ICRU	International Commission on Radiological Units and Measurements
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
IUPAC	International Union of Pure and Applied Chemistry
IUPAP	International Union of Pure and Applied Physics
NBS	National Bureau of Standards
SAA	Standards Association of Australia
SAE	Society of Automotive Engineers
SI	Le Système International d'Unités
UTC	Coordinated Universal Time

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