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### HANFORD GUIDES

**VOLUME 2**

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DG-201-E

DESIGN GUIDE

FOR

INSTRUMENT TRANSFORMER APPLICATION

OCTOBER 1, 1956
DESIGN GUIDE

FOR

INSTRUMENT TRANSFORMER APPLICATION

1. Transformer Errors and Correction Factors

Instrument transformers have two inherent errors, ratio and phase angle errors. The marked ratio of a transformer appears on its nameplate, but in practice the true ratio deviates from this value and results in a ratio error. In the ideal case, the reversed secondary current or voltage vector would be exactly in phase with the primary vector, but again this is not true in practice. There is usually a small angle of difference between the two vectors and this phase angle is the second source of error. Ratio error affects the overall accuracy of all instruments used with the transformer. Phase angle affects the accuracy of wattmeters and similar devices, but does not affect that of voltmeters and ammeters. Furthermore, the magnitude of the effect which phase angle has on wattmeters, etc., is dependent upon the power factor of the metered load. Transformer errors are not constant, but depend upon the transformer burden. Transformers having high ratios are inherently more accurate than those with low ratios.

Ratio Correction Factor (RCF) is the factor by which the marked ratio must be multiplied in order to obtain the true ratio. As an example, if the true ratio does not deviate from the marked ratio by more than ±0.3 percent, then the RCF will fall between 0.997 and 1.003. This factor is useful when an instrument transformer is used with voltmeters and ammeters.

Designation of a Transformer Correction Factor (TCF) is an attempt to state in one number the effect of both ratio and phase angle errors on readings of wattmeters and similar devices. TCF is the factor by which the indicated wattmeter reading must be multiplied in order to obtain the true reading. For example, if the true reading of a wattmeter, when used with a particular transformer, does not deviate from the indicated reading by more than ±1.2%, then the TCF will fall between 0.988 and 1.012. It will be appreciated that when a wattmeter is used with both a current and a potential transformer, the wattmeter reading must be corrected by the product of the two transformer correction factors.

A phase-angle correction factor is sometimes mentioned. It is the factor by which an indicated wattmeter reading must be multiplied to correct for the effect of phase angle only. This factor equals the ratio of the true power factor to the apparent power factor. Ordinarily, TCF would be used because it includes the effect of both ratio error and phase angle.

-1-
2. **ASA Standard Accuracy Classes for Metering**

Since instrument transformer accuracy varies widely under different conditions of loading it is desirable to have some convenient means of classifying transformer performance in order to facilitate the selection of proper transformers for any particular application. A system has been devised and accepted as an American Standard Association (ASA) standard. The system provides a stepwise series of accuracy classes and a series of standard burdens.

The accuracy classes are 0.3, 0.6, and 1.2. For current transformers, 2.4 is also used. These numbers specify the percent accuracy as we commonly think of it; that is, class 0.6 implies that the accuracy is not worse than \( \pm 0.6\% \), but is not as good as 0.3%. The accuracy classes refer to the limits of transformer correction factor, and therefore, include the combined effect of both phase angle and ratio error which, often as not, may be compensating. The extent of compensation is limited by specifying that neither the RCF nor the TCF shall exceed the limits inferred by the accuracy classification. In other words, an accuracy class 0.3 denotes a transformer of such accuracy that neither ratio error alone, nor combined ratio and phase angle error exceeds \( \pm 0.3\% \).

Certain limitations are imposed. In the case of potential transformers, the voltage is specified to be within \( \pm 10\% \) of normal voltage. Current transformers are specified to be at 100% load, and the accuracy must not fall outside the next lower class at 10% load. The metered load power factor must be between 0.6 lagging and 1.0.

It is an inherent feature of transformers that the errors increase as the burden increases, and decreases as the ratio increases. It is for these reasons that any particular type of transformer will be more accurate in the higher ratios, and any specific transformer may be listed in a lower standard accuracy class at higher burdens.

3. **ASA Standard Burdens**

Transformer errors depend upon secondary burden, so that it is not sufficient to specify an accuracy class without specifying the burden. Certain burdens have been accepted as an American standard. These burdens cover the usual range of metering and relay applications, but it must be understood that actual applied burdens will seldom be exactly equal to a standard burden. Relaying applications may impose substantially higher burdens than those required by metering. Thus the first three current transformer burdens are primarily for the usual range of metering applications, while the last four are for relaying. Standard burdens are as shown below. It will be noted that the intervals are approximately logarithmic.
ASA Standard Accuracy Classes for Relaying

In relay applications the performance of a current transformer is of interest at many times normal current. As primary current increases, secondary current and voltage increase about in proportion to it up to the point at which the core begins to saturate, after which the errors increase drastically. The secondary flux linkages are proportional to the voltage required to circulate the current through the secondary impedance. Therefore, the criterion of excellence of a current transformer for relay service can be considered to be the value of the highest secondary voltage it can induce without saturation and consequent large errors.

A classification system has been devised and accepted as an ASA standard. There are two accuracy classes: 2.5 and 10 maximum ratio error; and there are seven standard voltage steps: 10, 20, 50, 100, 200, 400, and 800 volts, based on twenty times normal current. Thus if a current transformer bears a classification 10 (or L)100, it means that at twenty times normal current the transformer can induce 100 secondary volts without exceeding 10% ratio error. Since the classifications are in steps it is understood that the voltage limit may be higher than 100 volts, but not as high as 200 and still hold within the 10% error. Conversely, at 100 induced volts the ratio error may be less than 10% but not as low as 2.5%.

The H and L require explanation. If the rating is, for instance, 10H100 then at twenty times normal current (100 amperes), if 100 secondary volts is not to be exceeded, the burden must not be greater.
than 1 ohm. The same applies to a 10L100 rating. But with an H rating, as the current is reduced from twenty times normal down to five times normal, the burden can be proportionately increased so long as the secondary voltage limit is not exceeded. This does not hold true for the L rating, in which case the maximum burden at all lower currents is that calculated for twenty times normal current. In general, H ratings are more commonly used. Bushing transformers sometimes bear an L rating. The H and L letters were apparently chosen in reference to high and low internal impedance.

5. Application Notes - Accuracy and Burden

Applications requiring revenue metering have not been common at HAPO but may become so in the future. When used for this purpose the transformers should be ASA Class 0.3, and they should be of the type specifically designed for high accuracy over the range from light loads to moderate overloads. Burdens are usually light and it will not generally be necessary to specify higher than B-0.2 for CT's and burden X for PT's. Typical accuracy specifications would then be: ASA 0.3:B-0.1, 0.3:B-0.2 for CT's and ASA 0.3:W or 0.3:X for PT's.

Quite frequently transformers are required only for operating indicating instruments. Obviously it would be an error to require a 0.3 transformer to operate a 2% instrument. As a guide, consider:

- A 1% meter with a 1.2 transformer gives 2.2% overall accuracy.
- A 1% meter with a 0.6 transformer gives 1.6% overall accuracy.
- A 1% meter with a 0.3 transformer gives 1.3% overall accuracy.

- A 2% meter with a 2.4 transformer gives 4.4% overall accuracy.
- A 2% meter with a 1.2 transformer gives 3.2% overall accuracy.
- A 2% meter with a 0.6 transformer gives 2.6% overall accuracy.

It would probably be difficult to justify the use of transformers more accurate than 0.6 or even 1.2 for such applications where cost is a factor. Burdens are usually light. Order of magnitude burdens of switchboard devices are: ammeters and power-factor meters -- 0.02 ohms impedance; wattmeters and watthour meters -- 0.08 ohms; voltmeters, wattmeters and frequency meters -- 4 volt-amperes; watthour meters -- 10 va; power-factor meters -- 15 va. Recording meters may add burdens up to about 25 va. Thus, typical accuracy specifications might be: ASA 0.6: B-0.1, 1.2:B-0.2, 2.4:B-0.5 for CT's and 0.6:W, 0.6:X, 1.2:Y for PT's. These suggestions are for the lower ratio transformers, perhaps 200 amperes and less for CT's and 600 volts for PT's. As the ratios increase, accuracy specifications can be improved somewhat without incurring greater costs.

Accuracy specifications in HAPO Standard Specifications HWS-8001-S and HWS-8005-S for 600, 2400, and 13,800 volt switchgear follow the above suggestions except in the case of CT's for the higher voltages. In these cases the accuracy requirements were increased somewhat to provide for possible metering and relay applications, and to be commensurate with the quality usually furnished as standard equipment in such switchgear.
Relay burdens are commonly higher than meter burdens and the currents at which relays must operate are commonly several times the normal rating. Current transformers, in general, have rather large ratio errors at the combination of high current and high burden. At the high currents the relay core usually saturates so that it no longer has the same impedance. If the current transformer saturates as well as the relay, the wave shape of the current is very much distorted and the relay characteristic changes to an indefinite extent. Predictions of relay performance based on the overcurrent curves of a current transformer are therefore not valid if the transformer error exceeds 10 percent.

The transformer secondary voltage at which the error exceeds 10 percent depends upon the transformer burden, which in turn depends upon the relay application. Therefore no definite guide can be formulated for relay classification of current transformer performance. Some general notes may be worthy of consideration.

Overcurrent relays, in general, do not distinguish between values of current above five times the operating current and so it makes little difference if the secondary current is, say, only seven times instead of ten times normal.

In many applications of differential relay protection the current transformer errors may be of any magnitude, so long as they are the same in both transformers. However, each instance should receive individual consideration.

Impedance measuring relays will measure too high an impedance if the relay current is low. The relay setting can be adjusted to compensate for transformer error at any one operating point and fault condition, but the adjustment will be incorrect for all other values of fault. Compensation for current transformer error is therefore usually not practical.

6. **Mechanical, Thermal and Electrical Ratings**

In the application of instrument transformers it is necessary to consider mechanical, thermal, and electrical ratings in addition to accuracy.

Current transformers must be capable of withstanding the electromagnetic stresses caused by short circuit currents. ASA standard C-57 defines the mechanical limit in terms of the rms value of current which the transformer will carry, considering that it will be fully offset. Mechanical forces are not generally large enough to be important at currents less than 50 times normal. Transformers of window-type construction, properly installed, may have an almost unlimited mechanical rating. Wound types are commonly rated at or above 100 times normal current. Transformers intended primarily for switchgear applications may have much higher mechanical limits than those of transformers for other applications. Transformers in the lower ratios have lower mechanical limits than do those in higher ratios. Careful selection of low ratio transformers is necessary to assure ratings adequate for the application.
Both current and potential transformers have thermal ratings, and CT's also have a short time thermal limit. The short time thermal limit is based upon a maximum temperature of 250°C. A typical thermal limit might be 70 times normal for 1 second, but is usually much higher in CT's designed for switchgear applications. Continuous thermal ratings are based upon 55°C rise over 30°C ambient. Current transformers may also bear ratings based upon 55°C ambient, for example, those designed for switchgear application, in which case the 30°C ambient rating is about one-third higher.

ASA standards C-57 for instrument transformers adequately cover the various kv insulation classes and tabulate the various classes of standard ratios for current and potential transformers. It becomes a matter of critically examining and understanding the special and unusual applications in order to eliminate field trouble resulting from improper application.
DG-202-E

ELECTRICAL GUIDE

FOR

JOINT INDUSTRY CONFERENCE ELECTRICAL

STANDARDS FOR INDUSTRIAL EQUIPMENT

600 VOLTS AND LESS
ELECTRICAL GUIDE
FOR USE OF
JOINT INDUSTRY CONFERENCE (JIC) ELECTRICAL STANDARDS
FOR INDUSTRIAL EQUIPMENT - 600 VOLTS AND LESS

The JIC Standards were developed for machine tools by the following:

Industrial Electrical Engineering Society of Detroit (IEES)
Industrial Equipment Users
Industrial Heating Association Inc. (IHA)
National Electrical Manufacturers Association (NEMA)
National Machine Tool Buildings Association (NMTBA)
Resistance Welder Manufacturers Association (RWMA)

JIC Standards are approved for use at HAPO as a general procurement specification for metal cutting and forming tools, and other similar electrically powered or controlled non-critical equipment, including furnace, press and welding equipment (See JIC, Section E10, General). If so used, JIC Electrical Standards for Industrial Equipment shall be referenced as the applicable technical specification.

JIC Standards shall not be used for critical production equipment or equipment in hazardous locations. These applications require adherence to established HAPO Standards for wiring, conduits, grounding, branch circuit protection, etc.

There are certain discrepancies between the JIC Standards, and HAPO Standards and Design Criteria. It is emphasized that JIC applies only to wiring and control equipment integral with a machine tool and in no way changes or modifies existing HAPO practices external to the machine.

The following items should be shown on the Purchase Specification when JIC Standards are used:

A. Electrical equipment shall be in accordance with the JIC Electrical Standards for Industrial Equipment.

B. Power Supply
   1. The electrical characteristics of the power system to which the equipment is to be connected must be fully stated, i.e., voltage, phase, three or four wire, 60 cycle, alternating current or volts direct current.
2. The short circuit current of the a-c power system. State asymmetrical short circuit amperes.

C. Motors

1. Standard NEMA Design B motors in accordance with JIC Section E 23.2. will be furnished unless other construction is specified.

2. Specify type of motor starting required (across the line or reduced voltage).

D. Controls

1. Specify the type of supply circuit disconnecting device required.

2. Specify the panel location if separate from the machine and whether or not raceway and wiring is to be furnished between the machine and separately mounted enclosures.

3. Specify grounded or ungrounded control circuit. Grounded control circuits are preferred unless other considerations make grounding impractical.

E. Drawings

Include the following statements:

1. Within (blank) days after receipt of the Purchase Order, and prior to the start of fabrication, the vendor shall furnish for approval and correction, five (5) sets of the following in accordance with JIC Section E 10.6.
   a. Elementary diagram.
   b. Electrical stock list.
   c. A written sequence of operations.
   d. Electrical layout drawing.
   e. Connection diagram.
   f. Foundation drawing showing conduit locations if required.

2. Within (blank) days after receipt of the above approved drawings, the vendor shall furnish one certified set of all drawing reproducibles, as listed above.

3. Connection boxes on the equipment shall be clearly and completely identified on the drawings to indicate the size and function of the wiring.
F. The following are supplementary requirements for control enclosures where the enclosure is not located in the base or column of a machine i.e., separate enclosures.

1. Control or protective devices shall not be mounted to the side walls of the cabinet or enclosure. Only externally operated control devices shall be mounted on the door or front of the enclosure. Devices and wiring on doors shall not be energized at more than 125 volts.

2. A suitable means shall be provided to hold doors in the full open position.

G. General

1. Specify any conditions for which unusual provisions must be made, such as limited power supply, ambient temperature over 40 C, etc.

2. If all or any part of the equipment as specified by the foregoing is required design, it should be so stated and the reasons for these requirements fully explained.

3. In some applications where ventilation, heating or other important loads must be kept in operation, it will be necessary to specify branch circuit protection for individual circuits serving single or multiple loads to permit maintenance without deenergizing the entire machine. Such equipment shall be operable and lockable from the outside of the enclosure, and may be in the form of an integral or separate distribution panel.

H. Other JIC Requirements

The following are partial paragraph quotations from the Standard. If any of these provisions are not necessary or desirable, it shall be so stated in the Purchase Order and the actual requirements fully explained.
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<td>Control transformers shall have an extra capacity of 25% over the control requirements, but not less than 100 volt amps - etc.</td>
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<td>E15.3.5</td>
<td>No polyphase motor starter shall be smaller than NEMA, size 1.</td>
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<tr>
<td>E16.1.1</td>
<td>Control enclosures shall comply with NEMA, type 12 enclosure requirements.</td>
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<tr>
<td>E16.2.7</td>
<td>There shall be no holes in the enclosure for mounting the enclosure or mounting controls in the enclosure - etc.</td>
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<td>E16.2.10</td>
<td>Panel shall be forced-filtered air-ventilated when ventilated openings are necessary, and shall be so designed to prevent entrance of deleterious substances.</td>
</tr>
<tr>
<td>E16.3.1</td>
<td>A single-strip fluorescent lamp shall be provided in all enclosures, with panel areas over 1500 square inches in size.</td>
</tr>
<tr>
<td>E17.2.6</td>
<td>A minimum of 15% unused panel mounting space shall be provided on panels over 1500 square inches. A minimum of 30% unused space shall be provided on smaller panels.</td>
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<tr>
<td>E18.1.1</td>
<td>All indicating lights shall be oil-tight, push-to-test type, with integral transformers for 6 volt lamps.</td>
</tr>
<tr>
<td>E18.6.1</td>
<td>Indicating lamps shall be provided on transfer type machines to show position of mechanical components, such as clamps, transfer, etc.</td>
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<tr>
<td>E23.2.1</td>
<td>Where polyphase power is available, motors 1/4 hp and larger shall be polyphase.</td>
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<tr>
<td>E23.3.6</td>
<td>Motor mounting space shall be large enough to accommodate another motor, same speed, and 2 NEMA horsepower larger than the size recommended by the equipment manufacturers.</td>
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<tr>
<td>E24.6.4</td>
<td>All ungrounded control circuits shall be equipped with ground detector lights.</td>
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New 4-13-59
DESIGN INSTRUCTION FOR USE OF
GUIDE SPECIFICATION FOR ELECTRICAL CONSTRUCTION - DG-203-E

This Guide Specification is written in the construction specification style and arrangement, i.e., GENERAL, MATERIALS and WORKMANSHIP Sections including INSPECTION AND TESTING. It covers those items most commonly encountered in electrical construction. In using the Guide, the Engineer must delete all items that do not apply to the work in question, and add any special or unusual items as may be necessary. This Guide Specification must not be issued "as is" to lump-sum Contractors or to Vendors.

Blank spaces in the Guide are to be filled in with the appropriate information. Words in parentheses indicate a choice is necessary to fit individual conditions. The parentheses and non-applicable words should be marked out. Parenthetical phrases are notes to the Engineer and should, of course, be deleted in the construction specification. Applicable paragraphs should be used as nearly as possible as they appear in the Guide. The headings can then be numbered consistently with other Divisions of the job specification.

This Specification is not a design manual, and is not intended for all-purpose use in lieu of detailed design and construction drawings. For design information, see Hanford Standard Electrical Design Criteria.

Engineers who prepare construction specifications frequently will find it convenient to produce extra copies of the Guide to edit as necessary for each construction contract. Copies can be obtained from GE&UO, Reproduction, Building 760.
DG-203-E

GUIDE SPECIFICATION

FOR

ELECTRICAL CONSTRUCTION

DESIGN CRITERIA

GUIDE SPECIFICATION FOR
ELECTRICAL CONSTRUCTION

APPROVED BY ENGINEERING STANDARDS COUNCIL
H E Struck  SECRETARY DATE  12-19-58

REVISED AND ISSUED
Complete 6-10-63
26 Pages

DG-203-E
GUIDE SPECIFICATION FOR
ELECTRICAL CONSTRUCTION

DIVISION _______

ELECTRICAL

1. SCOPE

(Briefly outline the work covered. Describe items requiring special attention. Avoid itemizing work activity because this can be construed as a statement of work to be done by the Contractor and may result in conflict in the administration of the contract).

2. WORK NOT INCLUDED

(If the extent of the work needs clarification in addition to Section 1 above, indicate work which is not to be done. Indicate who will make connections to existing electrical systems. This section may also be used to indicate that certain parts of the work are covered in other divisions of the specifications).

3. SUBMISSION OF DRAWINGS AND INFORMATION

The Contractor shall furnish fabrication and shop drawings, circuit diagrams, performance data, and specifications for the (unit substation) (switchgear) (motor control center) (other), for comment and in final approved form in conformance with the Special Conditions.

4. CODES

The work shall conform to the National Electrical Code (NEC) 19__, the National Board of Fire Underwriter's (BNFU), 19__, Pamphlets 72 and 73, the National Electrical Safety Code (NESC) National Bureau of Standards Handbook 81, 19__ and supplements thereto. (Specify year of latest issue of all codes used.) Recommended methods and materials for installation of work as described in the above codes shall be mandatory unless otherwise specified herein or otherwise shown on the drawings or referenced Hanford Standards.

(Other information of a general nature pertaining to the Division should be stated here. The decimal numbering system is used. Main headings are underlined. Secondary headings are not underlined. Subdivisions - a, b, c, etc. should be used only where the information is logically divided into two or more subjects of equal importance.)

For example -

8. CONDUCTORS

8.1 GENERAL
8.2 BUILDING WIRE

a.
b.
STANDARDS FOR MATERIALS

Materials shall conform to the National Electrical Manufacturer's Association (NEMA) Standards if such standards have been established for the particular materials. Where materials and equipment have been examined and approved for the intended service by Underwriter's Laboratories, Inc., or other nationally recognized testing bureau approved by the Commission, the materials used shall bear the label of the laboratory or testing bureau or shall be listed as having been examined and approved by the laboratory or bureau.

POLES

Poles shall be Western red cedar cut from live stock and shall conform to American Standards Association, Specifications and Dimensions for Wool Poles, 05.1-19. All poles shall be conditioned and air-seasoned in accordance with the American Wood Preservers' Association (AWPA) Standard M1-19. All poles shall be incised above and below the standard ground line and butt treated with either creosote or pentachlorophenol-petroleum solution in accordance with AWPA Standard C1-19 and C4-19. Each pole shall be branded on the butt to designate the class and length of pole; and shall be branded on the face at about 6 feet above the standard ground line but not less than 12 feet above the butt. The face brand shall designate the supplier's code or trade-mark, plant location, and year of treatment, species and preservative code, class and length of pole. The pole roof and gain shall be brush coated with creosote conforming to AWPA Standard P1-19 or pentachlorophenol-petroleum solution conforming to AWPA Standard P8-19. Each pole shall have a gain on the face of the pole ½ inch deep by 4 3/4 inches in length with the center of gain 12 inches below the axis of roof cut. A 13/16 inch diameter thru hole shall be drilled at the center and square with the face of the gain. The top of each pole shall have a one-way roof cut sloping 30 degrees (120 degrees with pole axis) and the cut surface shall face at right angles to the pole face.

ANCHORS

Anchors shall conform to Hanford Standard D-4-1a, Concrete Cone Anchor.

GUY STRAND

All guy strand shall be galvanized steel as specified on the drawings.

LINE HARDWARE

All line hardware for framing assemblies shall be galvanized and shall be as shown or noted on the drawings, or approved equals.

INSULATORS

All primary insulators and strain insulators shall be EEI-NEMA Standard wet process porcelain with brown glaze. Insulators for high-voltage street and fence lighting circuits shall have a white glaze.
CROSSARMS

Crossarms shall conform to the Edison Electric Institute (EEI) Standard TD-90 and shall be as shown on Hanford Standard D-2-2a to D-2-2e.

CROSSARM BRACES

Crossarms carrying conductors larger than No. 1/0 Awg shall be supported by one piece steel angle braces.

LINE CONDUCTORS

All line conductors shall be of the type, size and material as shown on the drawings. Conductors of size No. 2 Awg and larger shall be stranded.

DISTRIBUTION TRANSFORMERS


UNIT SUBSTATIONS, (INDOOR) (OUTDOOR)-(---) VOLTS

The unit substation(s) shall comply with Hanford Specification HWS-_______, and the applicable drawings.

SWITCHGEAR, METAL-CLAD, (INDOOR) (OUTDOOR)-(---) VOLTS

Switchgear shall comply with Hanford Standard Specification (HWS-8001-S, 600 Volt) (HWS-8005-S, 4.16 and 13.8 KV) and the applicable drawings.

MOTORS

Squirrel-cage, induction motors - fractional to 200 HP - shall be in accordance with Hanford Standard Specification HWS-8009-S.

MOTOR CONTROL CENTERS - 600 VOLTS

Motor control center(s) shall consist of standardized prefabricated metal sections completely enclosing the control equipment and assembled to provide a dead front unit. Control centers shall conform to Hanford Standard Specification HWS-9000-S, Motor Control Centers - 600 Volts, and the applicable drawings.

MOTOR CONTROLLERS - 600 VOLTS

a. Magnetic motor starter(s) shall be the combination type in NEMA Type _____ enclosures with overload protection. For motors rated 3 horsepower and smaller, a 30 ampere fused disconnect shall be furnished and installed. For motors rated 5 horsepower and larger a circuit breaker, rated according to the National Electrical Code, shall be installed.

b. Manual motor starter(s) shall include overload protection and shall be in NEMA Type _______ enclosures.
MATERIALS (continued) CAPE-1872

PANELS, BRANCH CIRCUIT

a. Branch circuit panel(s) for (120/240 volt, single-phase) (208Y/120 or 240 volt, three-phase) systems shall be circuit breaker type lighting panel boards, General Electric Company, Type or an approved equal. Circuit breakers shall have an interrupting capacity of 7500 RMS amperes for bolt-in breakers and 5000 amperes for plug-in breakers.

b. Branch circuit panel(s) for 460Y/265 volt lighting systems shall be the circuit breaker type, General Electric Company, Type or an approved equal. Circuit breakers shall have an interrupting capacity of (10,000) RMS amperes. An equipment grounding terminal bar, similar to and in addition to the neutral bar, shall be installed in the panel enclosure.

DISTRIBUTION CENTERS - 480 VOLTS

Feeder distribution center(s) for (460) (460Y/256) volt, three-phase systems shall be General Electric Company, Type or approved equal. Circuit breakers (if used) shall have an interrupting capacity of ______RMS amperes. An equipment grounding terminal bar, similar and in addition to the neutral bar, shall be installed in the panel enclosure.

LIGHTING TRANSFORMER

Primary voltage of lighting transformer(s) shall be 480 volts with (number) % taps below normal. Secondary voltage shall be ______ volts. The transformer(s) shall be designed for continuous operation in 40 C ambient with a temperature rise not in excess of 80 C. The transformer(s) shall be General Electric Company or approved equal.

RACEWAYS, FITTINGS AND BOXES

a. Rigid steel conduit shall be hot dipped galvanized, zinc metalized, or sherardized conduit, and shall conform to Federal Specification WW-C-58ld. Conduit shall be furnished with an antifriction finish on the internal surfaces.

b. Rigid aluminum conduit (for use only in dry locations or where encased in concrete) shall conform to Federal Specification WW-C-540a.

c. Electric metallic tubing (EMT) shall be hot-dipped galvanized, zinc-metalized, or sherardized with an internal surface finish of antifriction lacquer and shall conform to Federal Specification WW-T-806b. Connectors and couplings shall be water tight. Indentor type fittings shall not be used.

d. Galvanized steel flexible conduit shall conform to Federal Specification WW-C-566b. Fittings for flexible steel conduit shall be galvanized.

e. Liquid-tight flexible conduit shall be the type with a built-in grounding conductor. Fittings for liquid-tight flexible conduit shall be Appleton Electric Company, Type ST or approved equal.
f. Unless shown otherwise on the drawings, the minimum size of conduit (or EMT) shall be 3/4 inch.

g. Boxes used with galvanized rigid conduit or EMT in dry locations shall be aluminum, galvanized steel, cast iron or cast aluminum.

h. Boxes used in wet or oily locations shall be cast steel or cast iron with corrosion resistant finish, threaded hubs and gasketed covers. Boxes shall conform to the Joint Industry Conference Electrical Standards for Industrial Equipment specifications for seal-tight fittings.

i. One-hole pipe straps used for supporting conduit shall be equipped with clamp-backs.

j. Deep-type concrete outlet boxes shall be used where conduits enter the sides in order to avoid interference with reinforcing steel.

k. Boxes used with non-metallic sheathed cable shall be aluminum or galvanized steel of a type especially designed for the purpose.

l. Unless specified otherwise on the drawings, outlet boxes for lighting fixtures where conduit is concealed shall be not smaller than four inch octagon boxes.

m. Boxes for switches and receptacles shall be one-piece pressed steel, 4 inches square by 1-1/2 inches deep minimum, for one or two devices. For flush mounting, 1-1/4 inch raised covers with rectangular openings for devices shall be used. Outlet boxes for switches and plug receptacles on unfinished walls where boxes cannot be concealed shall be set exposed with 1/2 inch raised surface covers to fit the device. Assemblies shall be in accordance with Hanford Standards D-20-110 and D-20-115.

n. Outlet boxes for telephone, signal, pushbutton and buzzer outlets shall have plastic covers with a rectangular opening in center. Each outlet shall have a plate with 3/8 inch bushed opening in center.

o. Fiber conduit shall be Orangeburg or approved equal and shall conform to Federal Specification W-C-581. Asbestos-cement conduit shall be equal to that manufactured by Johns-Manville and shall meet the requirements of Federal Specification W-C-571b.

p. Cable trays and fittings shall be hot-dipped galvanized steel or aluminum. All bolts and nuts used for support and assembly shall be non-corrosive and shall not project into the cable space except for large radius, 3/4 inch minimum, bolt heads.

q. Ducts and fittings shall have (hinged) (screw) covers and shall be the Square D Company "Lay-in-Duct", or approved equal.

r. (Ducts) (gutters) shall be constructed of galvanized sheet steel. Removable covers shall be secured by screws not smaller than 1/4 inch diameter. The cover shall have keyhole slots to allow removal of the cover without removing the screws. Maximum length of any one cover shall be four feet. Maximum spacing of cover screws shall be 12 inches.
MATERIALS (continued) CAFE - 1072 -

Cover screws, couplings and fittings shall not extend into the duct and shall not have sharp edges or points. Struts, spaced not more than four feet apart, shall be fixed across the open side in order to maintain rigidity.

s. Bus duct shall be __________________________, or approved equal. (Specify the particular design, conventional or low reactance type, type of insulation, type of housing and special details of support or installation.)

t. Ducts, gutters, cable trays, banks of conduits, or other raceways and equipment shall be supported on hangers made for the purpose, or on built-up metal framing such as "Unistrut", "Kindorff", or approved equal.

u. Except as specified herein or otherwise shown on the drawings, standard outlet boxes, covers plates and fittings shall be used for building and process wiring.

CONDUCTORS

GENERAL

Wire and cable shall be new and of the type specified herein. Size and number of conductors shall be as shown on the drawings. Wire and cable shall have been manufactured since ______________________ (month and year).

BUILDING WIRE - 600 VOLT

a. Single conductor building and process wire shall conform to Hanford Standard D-20-1 for type, size, insulation thickness, stranding and color codes. (If Standard D-20-1 is referenced, the following paragraphs b, c and d may be omitted provided the type of wire, including insulation thickness, is stated for each of the wiring systems involved either in the specification or on the drawings).

b. Thermoplastic insulated wire shall conform to Hanford Standard Specification HWS-8002-S, Thermoplastic Insulated Wire and Cable. The insulation thickness of Type TW and THW wire shall be in accordance with the Insulated Power Cable Engineers Association (IPCEA) Standard S-19-51, Feb. 1951, Appendix I, Table I, as follows:

<table>
<thead>
<tr>
<th>Size Awg or MCM</th>
<th>Thickness in 64th Inch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Column A</td>
</tr>
<tr>
<td></td>
<td>Type TW</td>
</tr>
<tr>
<td>18-10</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>6-2</td>
<td>4</td>
</tr>
<tr>
<td>1-4/0</td>
<td>5</td>
</tr>
<tr>
<td>225-500</td>
<td>6</td>
</tr>
</tbody>
</table>

Column A shall be used for (list systems) (non-process) wiring in recognized metal raceways. Column B shall be used for (list systems) (process) wiring in recognized metal raceways. Column C shall be
used (in underground ducts) (for direct burial). In any system, the green equipment ground conductor need not have insulation thickness greater than that shown in Column A.

c. Synthetic rubber insulated cable with polychloroprene or polyvinyl chloride jacket, Type RHW, shall be used for (list systems) (all process service and power conductors) in sizes No. 1/0 Awg and larger, and shall conform to Hanford Standard Specification HWS-8003-S, Synthetic Rubber Insulated Wire and Cable - 600 Volt.

d. The minimum wire size for lighting and power circuits shall be No. 12 Awg. Unless otherwise specified, wire sizes No. 8 and larger shall be stranded and No. 10 and smaller may be solid, except that all control wire and equipment grounding conductors shall be stranded. All conductors shall be copper, unless shown otherwise on the drawings.

_3_ NON-METALLIC SHEATHED CABLE

Non-metallic sheathed cable shall conform to Federal Specification J-3-94b Type NMC, Grade VI. Cable connectors shall be corrosion resistant with a positive pressure connection on the cable.

_4_ MULTI-CONDUCTOR CONTROL CABLE

Multiple conductor cable shall be No.______Awg stranded conductor, (300)(600) volt, with thermoplastic insulation and jacket and shall conform to Hanford Standard Specification HWS-8004-S, and Hanford Standard D-20-5.

_5_ WIRE MARKERS

Identification marking of individual conductors, where required by the drawings, shall be by imprinted tubular plastic wire markers. Unless otherwise specified, the marker shall be white or yellow with black characters.

_6_ HIGH VOLTAGE CABLE

High voltage cables shall be insulated with a butyl rubber compound and shall have a neoprene or polyvinyl chloride jacket. Cables shall be (single) (multiple) conductor (shielded) (non-shielded) and shall conform to Hanford Standard Specification HWS-8006-S, Butyl Rubber Insulated Jacketed Cable - 5 and 15 KV.

_7_ INTERLOCKED ARMOR CABLE

Armored cable shall conform to Hanford Standard Specification HWS-8007-S, Interlocked Armor Cable - 600 Volt, 5 and 15 KV. All splicing and terminating fittings shall be compatible with the cable and according to the manufacturer's recommendations.
MATERIALS (continued)

8 GALVANIZED GROUNDING CONDUCTOR

All grounding conductors, buried in the earth or encased in concrete, shall be steel strand wire, Common Grade, with Class B zinc coating in accordance with ASTM Specification A475. All above grade or exposed grounding conductors shall be copper cable. Sizes shall be as shown on the drawings.

SOLDERLESS CONNECTORS

Pressure type solderless connectors and terminal lugs for use with building wiring not exceeding 600 volts between conductors, shall be the following or approved equals.

For conductors No. 8 Awg and smaller

(1) Ideal Industries, Inc. - Ideal Set Screw Type
(2) Burndy Engineering Co. - "Hydent"
(3) Minnesota Mining & Mfg. Co. - "Scotchlok"

For conductors No. 6 Awg and larger

(1) Burndy Engineering Co. - "Hydent" or Screw Pressure Connectors
(2) Erico Products, Inc. - "Cadweld" connections.

RECEPTACLES AND PLUGS

Details of, and connections to, the receptacles and plugs shall be as shown on Hanford Standard(s) as follows:

a. For 120 volt, single-phase service.

(3) Outlets where cord is in tension - polarized, three-pole, twist-lock, 15 ampere, Standard D-20-23.

b. For 120/240, 120/208, 240, and 208 volt, single-phase service.

(1) Convenience outlets - 15 ampere, 208 or 240 volt, Standard D-20-40.
(2) 20 ampere, 120/208 or 120/240 volt, Standard D-20-45.

*Only products of other manufactures which are directly interchangeable with the above are permitted.
MATERIALS (continued)

(4) Range receptacle, 50 ampere, 240 volts with external grounding clips, Standard D-20-50.

(5) 60 ampere, 120/240 volts, Standard D-20-51.

c. For 277 volt, single-phase service.

(1) 15 ampere, 277 volt, Standard D-20-55.

d. For 460 volt, three-phase service, with grounding pole.

(1) 20 ampere, Russell and Stoll Co., "Ever-lok"* series.


(3) 100 ampere with interlocked fusible switch-Crouse Hinds Co., No. WMS-1610345*, Standard D-20-80.

e. Receptacle assemblies shall be as shown on Hanford Standard D-20-115.

LIGHTING FIXTURES

a. Lighting fixtures shall be furnished complete with lamps.

b. Incandescent lamps shall be rated at 120 volts, a.c. All exposed lamps shall be inside frosted unless shown otherwise on the drawings.

c. Fluorescent tubes shall be Standard Cool White color.

d. Ballasts for fluorescent lamps of 40 watts or more shall be protected against overheating by a built-in, thermally actuated, automatic reclosing device sensitive to both winding temperatures and current which shall prevent winding temperatures from exceeding 120 degrees centigrade. Under normal conditions and in a 40 C ambient temperature, the protector shall allow the windings to reach a minimum temperature of 105 C without opening the circuit to the primary winding. After opening the protector shall reclose at a case temperature of 85 C.

LIGHTING SWITCH ASSEMBLIES

Lighting switches, boxes, covers and plates shall be as shown on Hanford Standard D-20-110.

STORAGE BATTERIES

a. Storage batteries for (control of switchgear) (emergency service) (telephone exchange) (fire station) shall be the lead-acid type as made by the (Electric Storage Battery Company, Exide-Tytex or Exide Ironclad), (other) or approved equal.

ROOM TEMPERATURE CONTROLS

Thermostats (and relays) for room temperature control shall be as shown on the drawings.

*Only products of other manufactures which are directly interchangeable with the above are permitted.
GENERAL

a. Adequate mountings and supports for all equipment shall be provided. Supports attached to structural steel shall be clamped or welded. Drilling of holes in structural members will not be permitted.

b. All welding shall be in accord with the Division WELDING.

HANDLING AND SETTING POLES

a. Poles shall be carefully unloaded and handled to avoid damage. They shall be hauled to location and not dragged over the ground or paved surfaces. Construction hooks, tongs, or other sharp tools shall not be used on treated portions of poles.

b. If poles are to be stored for longer than two weeks they shall be stacked carefully upon supports at least one foot above ground. Strength and spacing of supports and manner of piling shall be such that no noticeable distortion will be produced in poles so stored.

c. Preframed and treated poles shall be placed and oriented to comply with facing requirements of crossarms specified under Installing Crossarms. Additional framing including gains, butt cuts and re-roofing that may be required shall be brush treated with creosote conforming to American Wood Preservers' Association Standard P1-19, or pentachlorophenol-petroleum solution in accordance with AWPA Standard P8-19.

d. Holes shall be dug large enough to admit a tamping bar all around pole at the butt. Explosives shall not be used to put down poles.

e. Backfill shall be made with material which can be solidly compacted by hand tamping in six inch lifts. Surplus earth shall be compacted around the pole in a cone one foot high. Where the backfill has settled, additional backfill shall be placed and tamped before completion of the work.

f. Poles shall be set plumb and in line, except that corners and strain points which are guyed shall have butts displaced to keep the tops in line.

INSTALLING CROSSARMS

Crossarms shall face each other on alternate spans on level construction. Crossarms shall be mounted at right angles to the axis of the poles. They shall be at right angles to the line on tangents, but shall bisect the angle where a line departs from a straight line. Double arms shall be used where required for extra strain at angles, dead ends, railroad and communication line crossings as required by the codes or as specified on drawings.
WORKMANSHIP (continued)  CAPE-1072-

**INSTALLING HARDWARE**

Bolts shall be of sufficient length for full thread engagement of the nut, but shall not protrude through poles or arms in excess of two inches. Bolt ends shall not be cut off. Square washers shall be used with each through-bolt and double-arming bolt.

**INSTALLING INSULATORS**

Pin insulators shall be tightened on the pin threads and top groove shall be adjusted parallel to the line. Insulator pins shall be steel. Holding nuts shall be made secure.

**INSTALLING GUYS AND ANCHORS**

a. Backfill around anchors shall be thoroughly compacted throughout the entire depth of the hole.

(Paragraph (b) may be omitted where any of the Standards in paragraph (c) are referenced).

b. Where possible, down guys shall be installed at an angle of 45 degrees. Guy rods set in earth shall be in line with the strand and shall have not less than 6 inches nor more than 12 inches of rod length exposed. All anchor rods shall have double thimble eyes. Down guys shall be provided with steel guy guards in traffic areas.

c. Guys and anchors shall be installed according to Hanford Standard(s) (D-4-1b), (D-4-1c), (D-4-1d), (D-4-1e), (D-4-1f).

**STRINGING CONDUCTORS**

a. Conductors shall be strung from reels. They shall not be dragged over the ground or permitted to lie where they may be damaged. Conductors shall be pulled through stringing sheaves and over rounded surfaces on crossarms and racks. Coils shall be inspected as they leave the reels and any weak or damaged sections shall be cut out and the ends spliced. Splices shall not be made in adjacent spans, dead end spans, or within four feet of a crossarm or support. Conductors shall be strung and tied to proper stringing tension in accordance with the sag tables furnished.

b. All splices under tension shall be made mechanically and electrically secure by means of compression fittings. Self-gripping or automatic tension splicing sleeves shall not be used. Taps between primary wires, jumpers, etc., shall be made with mechanical connectors. Dead ends on disc-type insulators shall be by means of straight line clamps.

c. Line conductors shall be tied in the top groove of pin-type insulators in the line, and on the side against strain at angles. Tie materials, sizes and lengths for various conductors and methods of tying shall be as shown or noted on the drawings.

d. Jumpers and taps shall be of kind and size equal to the smaller conductors of the tap line.
INSTALLING DISTRIBUTION TRANSFORMERS

Single-phase transformers shall be connected (for three-phase) as shown on Hanford Standard(s) (D-7-200a), (D-7-200b), (D-7-200c), (D-7-200d), (D-7-200e), (D-7-200f).

INSTALLING POLE LINE GROUNDS

Ground installations for aerial power distribution and telephone lines shall conform to Hanford Standard (D-3-3) (D-3-3'a), (D-3-3b), (D-3-3c). Grounds for pole-mounted fire alarm boxes shall conform to Hanford Standard (D-3-4) (D-3-4a).

INSTALLING BUILDING GROUNDING SYSTEMS

1. UNDERGROUND ELECTRODES AND CONNECTIONS

   a. Grounding shall be by means of (driven ground electrodes) (underground water main) (ground grid) in accordance with the drawings.

   b. Ground rods shall be of galvanized steel not less than 5/8 inch in diameter by eight feet in length. They shall be driven at least six feet apart in areas where a number of rods are needed to reduce ground resistance. Resistance to ground shall be measured by the volt-ammeter or Wheatstone bridge methods or by commercial instruments designed for measuring ground resistance.

   c. Building ground bus and grids shall be installed in accordance with Standards D-20-9b and D-20-9c.

   d. Buried grounding cable shall be protected against all mechanical damage before and during backfill. Backfill material within one foot of the cable shall not contain rocks larger than two inches in diameter.

   e. Splices and taps in galvanized steel grounding conductors that are to be buried in earth or concrete shall be made as follows:

      (1) Two pressure type clamps made of galvanized steel, or
      (2) Cast copper connections, "Cadweld Process" or approved equal.

      Welded connections shall be completely covered with asphaltic paint a distance of six inches from the connection.

   f. Where it is necessary to join a copper conductor to a galvanized steel conductor or to any steel, the joint shall be made above the ground in a dry location.

   g. The resistance of ground system joints and taps shall not be greater than the resistance of the same length of continuous conductor.

2. SYSTEM AND EQUIPMENT GROUNDING

   a. The neutral conductor of single-phase and three-phase, wye-connected distribution systems shall be grounded (at the transformer bank) (at the service entrance disconnecting device) only. (See Standard D-20-9).
b. Grounding methods shall be according to the following Hanford Standards, D-20-10 series, System and Equipment Grounding - A-C Systems - 600 volts and under.

- D-20-10 Basic Requirements and Conductors
- D-20-10a Services, Panels, and Conduits
- D-20-10b 120/240 and 120/208 Volt Systems
- D-20-10c 480 and 277/480 Volt Systems
- D-20-10d Ground Conductor Connections

(Paragraphs (c) through (i) may be omitted where Standards D-20-10, 10a, and D-20-10b or 10c are referenced).

c. The building service grounding conductor shall be enclosed in (rigid steel conduit) (electrical metallic tubing). Conduit shall be continuous from the service equipment to the grounding electrode and the grounding conductor shall be securely connected to the conduit at both ends, as shown on Hanford Standard D-20-10c.

d. The service ground connection shall be visible where above ground. Soldered connections shall not be used. "Cadmewd" or brazed ground connections are permitted.

e. In this specification and the drawings the term 'equipment' shall be understood to mean all exposed metal parts of a wiring system including conduit, raceways, metal armor of cables, cabinets, switch boxes, outlet boxes, motor frames, motor controllers, panel boards, lighting fixtures, etc.

f. The equipment ground conductor, where required under this specification and the drawings, shall be carried to all equipment in the same conduit or raceway with the power (and neutral) conductors. The grounding conductor shall in no case be the system neutral or any current carrying conductor.

g. All metallic conduits, wiring channels, and the armor of armored cable shall be connected at each end to the grounding conductor or firmly attached at each end, with a good electrical contact, to a properly grounded connection box. Ground connections must be made to the grounding conductor at each box.

h. Portable electrical equipment shall be grounded by means of a separate green colored grounding conductor in the cord or cable equal in current-carrying capacity to the largest line conductor. The ground shall be completed through a separate grounding pole in the plug and receptacle.

i. A continuous row of lighting fixtures supplied at less than 150 volts to ground may be considered as one fixture if the mechanical connections between fixtures are such that electrical continuity is assured. Fixtures supplied at over 150 volts to ground shall have a grounding conductor connected to each unit.

j. Plug-in or trolley busways shall have an internal grounding bus, and the plug or trolley devices shall have contact tabs or trolleys for making contact with this grounding bus. The grounding bus shall be positively connected to the grounding conductor at the point of supply and shall make positive electrical contact with the bus enclosure at both ends of the bus run and at intervals of 20 feet or less.
_3 STATIC GROUNDING AND LIGHTNING PROTECTION

a. The steel column footings of the buildings(s) (other metal structures) shall be thoroughly grounded to a water line or ground mat.

b. The building(s) shall have siding and roofing panels grounded at every fourth panel or sheet, and other building steel such as (floor gratings), (door frames), (railroad track) in and adjacent to the building shall be connected to the grounding system. (For hazardous locations - Class I, Division 1 only).

c. All non-electrical machinery and equipment (list locations and items) shall be grounded by means of bonding between each piece of equipment and a common connection to a grounded building column or directly to a water main. (For hazardous locations only).

d. Air terminals or lightning rods shall be connected to earth by the most direct external path possible. Sharp bends in the grounding conductors shall be avoided.

INSTALLING BUILDING SERVICES

a. Phase identification of aerial and service drop cables having ribbed markers in insulation or jacket shall conform to Hanford Standard D-4-20.

b. Service conduits shall be terminated in a service head with an insulating cover of a type which separates the conductors. Three feet of conductor shall be left extending from the service head for connections to the utility service drop. A service rack shall be installed adjacent to the service head for terminating the service drop.

c. Conduit shall be installed underground as shown on the drawings. The conduit(s) shall be (rigid galvanized steel), (Type I asbestos-cement), (Type I fibre) with (end bell) (bushing terminations) in the (manhole) (cable pit). Conduit risers shall terminate in a service head. See Section Installing Conduits.

INSTALLING UNIT SUBSTATION(S), SWITCHGEAR, AND MOTOR CONTROL CENTER(S)

a. Installation of (unit substations), (switchgear), and (motor control centers) shall be according to the equipment manufacturer's instructions and as detailed on the drawings.

b. Channel rails or floor frame for switchgear with roll out circuit breakers shall be set and leveled to permit the rolling carriage to enter the cubicle without a lift of more than 1/8 inch.

c. The concrete floor in the switchgear room shall be held level to a tolerance of 1/4 inch for the entire area under the switchgear plus two feet outward from cubicle fronts.
d. Cable and bus conductors in (switchgear), (motor control centers), (panels), and inter-connections to such equipment, shall be installed with phase sequence as follows when observed from the front.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Front</th>
<th>Left</th>
<th>Top</th>
<th>Upper Front</th>
<th>Upper Front</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Front</td>
<td>Left</td>
<td>Top</td>
<td>Upper Front</td>
<td>Upper Front</td>
</tr>
<tr>
<td>B</td>
<td>Center</td>
<td>Center</td>
<td>Center</td>
<td>Upper Rear</td>
<td>Lower Front</td>
</tr>
<tr>
<td>C</td>
<td>Rear</td>
<td>Right</td>
<td>Bottom</td>
<td>Lower Front</td>
<td>Lower Rear</td>
</tr>
</tbody>
</table>

**INSTALLING DISTRIBUTION AND BRANCH CIRCUIT PANEL(S)**

a. Unless specified otherwise, panels shall be mounted with the upper trip handle at a level of 5 feet, 6 inches.

b. Circuits shall be connected to the disconnecting devices as shown on the drawings.

c. A panel directory shall be provided to identify the equipment served by each circuit.

**INSTALLING DRY TRANSFORMERS**

Wall mounted transformers shall be supported only from (reinforced concrete walls) (structural steel members) (other). The primary feeder to dry transformers shall be connected to the taps selected by the Commission.

**IDENTIFYING EQUIPMENT**

The (main service equipment), (feeder panels), (branch circuit panels) (controllers), (motor control centers) and (switchgear) shall be properly identified after installation by means of lettering on, or by nameplates attached to such equipment. This identification shall include the designation, use, voltage, and number of phases.

**INSTALLING CONDUITS**

a. Concealed conduits shall be run in as directly and with as long bend radii as possible. Exposed conduits shall be run parallel to or at right angles with the lines of the building.

b. All conduit field bends shall be made with standard bending devices and shall have an inner edge radius not less than specified in the National Electrical Code. All bends shall be free of dents or flattening and shall be capable of passing metal mandrels, with hemispherical ends, conforming to the following dimensions:

<table>
<thead>
<tr>
<th>SIZE OF CONDUIT</th>
<th>MANDREL DIAMETER</th>
<th>MANDREL LENGTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/4</td>
<td>0.62</td>
<td>1.24</td>
</tr>
<tr>
<td>1</td>
<td>0.78</td>
<td>1.57</td>
</tr>
<tr>
<td>1-1/4</td>
<td>1.03</td>
<td>2.07</td>
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<tr>
<td>1-1/2</td>
<td>1.20</td>
<td>2.42</td>
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<tr>
<td>2</td>
<td>1.55</td>
<td>3.10</td>
</tr>
<tr>
<td>2-1/2</td>
<td>1.95</td>
<td>3.70</td>
</tr>
<tr>
<td>3</td>
<td>2.30</td>
<td>4.60</td>
</tr>
<tr>
<td>4</td>
<td>3.00</td>
<td>6.00</td>
</tr>
</tbody>
</table>
c. Conduit shall be cut square, reamed, have burrs removed, and shall be cleaned before the introduction of wires or cables. Immediately after installation, all conduit ends shall be plugged or capped with standard conduit accessories until wires are pulled.

d. Conduit joints shall be set up tight. Hangers and fastenings shall be secure and of a type appropriate in design and dimensions for the particular application. Maximum distance between supports shall be 7 feet for 3/4 inch conduit or smaller and 10 feet for one inch conduit and larger. Runs shall be straight and plumb. Elbows, offsets and bends shall be uniform and symmetrical.

e. Couplings, connectors and fittings shall be as specified herein or on the drawings and shall be installed to provide a rigid mechanical assembly and positive electrical conductivity.

f. Galvanized steel locknuts and bushings shall be used for attachment to enclosures unless a threaded hub is provided. In addition, ground wedges or bushings shall be installed as required by the grounding standards referenced in Section System and Equipment Grounding. Threadless fittings are not permitted for rigid conduit unless specifically indicated on the drawings. Ericson type couplings shall be used where required. Running threads are not permitted.

g. One-hole pipe straps used for supporting conduit shall be equipped with clamp-backs.

h. Conduits for building wiring, shall be run without moisture traps where possible. Where dips are unavoidable, a pull box or condulet with a drilled hole shall be placed at each low point for drainage.

i. The use of EMT is permitted only for wiring in wood frame buildings or exposed wiring in masonry, concrete, or steel frame buildings. EMT shall not be used in runs from the building wall or ceiling to machinery, or exposed vertical runs through floors. EMT shall not be used for service feeders.

j. Rigid metallic conduit shall be used where embedded in masonry or concrete building construction. Under-slab runs of conduit shall be encased in concrete of three inches minimum thickness on all sides of the conduit.

k. Flexible conduit is permitted in sections three feet or less to make connections to motors or other equipment where the use of rigid conduit is impractical.

l. Liquid-tight flexible metal conduit and fittings shall be used (list locations) (as shown on the drawings).

n. Type I asbestos-cement or fiber conduit shall be used only where encased in concrete.

o. Conduit runs through outside walls and long runs between areas where an air pressure differential exists shall be sealed at both ends to prevent the flow of air through the conduit and consequent condensation of moisture on the inside surface of the conduit, (except where ventilation is desired - pole risers for example). Duct sealing compounds such as "Duct-Seal", "Duxeal", or "Kerite" putty, or approved equal, shall be used for this purpose.

p. All spare conduit runs shall have galvanized steel or copper pull wires installed.

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INSTALLING METAL RACEWAYS

a. Cable trays, wireways, and metal ducts shall be installed complete with the necessary fittings, connectors and parts according to the recommendations of the manufacturer.

b. All parts of cable trays, wireways, and metal ducts shall be assembled accurately and supported firmly. Supports shall be spaced not less than (five) (other) feet apart unless, specifically shown otherwise on the drawings. Manufactured sections and fittings shall be used wherever possible. Field cuts or alterations shall be made in the manner prescribed by the manufacturer.

c. Cable trays, wireways, and metal ducts shall be free of all obstructions, burrs and sharp edges, and shall present a smooth surface for introduction of cable and wire.

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INSTALLING CONDUCTORS

a. Building wiring shall be installed and color coded as shown on Standard D-20-1. (Paragraphs (b) and (c) may be omitted where Standard D-20-1 is referenced).

b. Wire smaller than No. 12 Awg shall not be installed unless specifically indicated on the drawings, except that No. 14 stranded may be used for fire alarm and other signaling circuits, and interior wiring in control panels.

c. Circuit conductor color coding shall be:

<table>
<thead>
<tr>
<th>Single-Phase</th>
<th>Three-Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot No. 1 - Black</td>
<td>A Phase - Red</td>
</tr>
<tr>
<td>Hot No. 2 - Red</td>
<td>B Phase - Yellow or Orange</td>
</tr>
<tr>
<td>Neutral - White</td>
<td>C Phase - Blue or Black</td>
</tr>
<tr>
<td>Ground - Green or Bare</td>
<td>Neutral - White</td>
</tr>
<tr>
<td></td>
<td>Ground - Green or Bare</td>
</tr>
</tbody>
</table>

Pressure-sensitive plastic colored tape may be used to identify the conductors in lieu of colored insulation. Tape marking shall be applied.
at each junction and outlet box and shall be a minimum of two inches in width. Color coding shall be maintained throughout each wiring system to the connection box at the point of utilization.

d. Conductors with thermoplastic insulation or jacket shall not be installed or handled when the temperature of the wire or air temperature of the working area is 15°F or below.

e. All power, control and instrumentation conductors run in cable trays or ducts shall be grouped according to wire run schedules shown on the drawings. Grouping shall be performed by tying or strapping the conductors together to effect an orderly arrangement of conductors in the trays or ducts. Conductor groups so run shall not be allowed to entangle with adjacent groups but shall lie parallel with them.

f. Exposed conductors dropped from trays or racks to equipment shall be supported with approved type cable clamps. The conductors shall be grouped in an orderly manner and not be allowed to sag or droop.

g. The conductors terminating at each outlet shall be left not less than eight inches long for installation of devices or fixtures. Where conductors are spliced or pass through pull or junction boxes, sufficient extra length shall be provided for easy access to the conductors.

h. Powdered soapstone or other approved manufactured compounds shall be used where a lubricant is required for pulling in wire and cable.

i. Cable supports shall be installed for all vertical feeders at intervals not less than that shown in the National Electric Code. The cable supports shall be of the split wedge type which clamps each conductor.

j. Multiple-conductor control cable shall be installed and color coded in accordance with Hanford Standard D-20-5.

k. The terminations of conductors in the (list systems) shall be marked with a number to correspond to the wiring diagram. The marking shall be by means of imprinted tubular plastic wire markers.

l. Motor control wiring shall conform to Hanford Standard D-20-100 (specify with or without use of control transformer(s) if not shown on drawings.)

**INSTALLING DIRECT BURIAL CABLE**

Cables, where specifically shown on the drawings as direct burial runs, shall be installed in accordance with Hanford Standard D-15-75. Underground runs shall be permanently marked with marker posts conforming to Hanford Standard D-15-48.

**MAKING SPLICES, TAPS AND CABLE TERMINATIONS**

a. Splices and taps in 600 volt building wire No. 8 Awg and smaller shall be made mechanically strong, soldered and taped except that any of the
solderless connectors described under Section ______, Solderless Connectors, may be substituted. For conductors No. 6 and larger, joints shall be made with connectors, tees, lugs, etc. as described under the above paragraph.

b. Solderless connections shall be used according to the manufacturer's instructions. For connector types which require installation tools, the proper tool made especially for the connector shall be used.

c. Plastic insulating tape made especially for electrical work shall be used for all splices and taps on circuits up to 600 volts. The thickness of tape insulation shall be at least equal to that of conductor insulation. Where a bolted splice or connection presents an irregular surface, an insulating putty, "Scotchfil" or approved equal, shall be applied to the joints before taping.

d. Manufacturer's instructions and directions shall be strictly adhered to for splices, stress cones and terminations for cables operating at over 600 volts to ground.

e. Cable leads to oil-immersed equipment shall be treated to prevent capillary seepage of the oil into the cable insulation.

**INSTALLING INTERLOCKED ARMOR CABLE**

Armored cable shall be installed in cable trays as indicated on the drawings. Cables shall be strapped in place on all runs with a slope greater than 30 degrees from the horizontal. Insulation of joints and connectors shall be according to the manufacturer's instructions (and as detailed on the drawings).

**INSTALLING PLUG-IN-BUS**

The system shall be installed complete with all fittings, enclosures, insulating and supporting members. All parts shall be of the same manufacture. Assembly and installation shall be made according to the manufacturer's recommendations. Bus plugs shall be installed at locations shown on the drawings.

**LOCATION OF EQUIPMENT**

Unless locations of pull boxes, switches and other small equipment are dimensioned on the drawings, such locations shall be considered as approximate. The Contractor shall verify critical dimensions as shown on the drawings and shall take all field measurements necessary to prepare shop drawings as required for installation of the work.

**INSTALLING BOXES AND WIRING DEVICES**

a. Boxes shall be sized and installed in accordance with the National Electrical Code, unless larger sizes are shown on the drawings.

b. Boxes shall have only the required openings to accommodate the conduits or cables entering the box.
c. Bracket outlets shall be set 6 feet, 6 inches from floor. When located on columns or over doors they shall be set symmetrical with columns or door.

d. Telephone wall outlets shall be set flush in wall 18 inches above finished floor unless otherwise noted. Signal outlets shall be flush in wall (18 inches above floor) (near ceiling) (as indicated by symbol or noted on the drawings.)

e. In conduit systems, duplex grounding-type receptacles, where mounted on flat or raised covers, Steel City RS series or similar types, by means of the single screw intended for attachment of a cover plate and where the yoke ears are not attached to the box, shall have a green colored bonding conductor run from the receptacle ground screw to the box, a conduit ground wedge, or a conduit bushing grounding screw.

f. All boxes shall be rigidly secured in position. Concealed boxes shall be set so that the front edge of box or cover is flush with finished wall or ceiling line or not more than one-fourth inch back of same.

g. Outlet boxes, panels, or other electrical equipment must be located at least 10 feet from safety showers, unless such equipment is located eight feet or more above the floor.

h. Lighting switches shall be mounted 4 feet above the floor. Convenience outlets shall be located 18 inches above the floor except in shops or similar areas where the mounting height shall be 4 feet above the floor. Mounting heights for switches and receptacles in prefabricated metal partitions shall be according to the partition manufacturer's standard. Cover plates on switches and receptacles shall be metal except that non-metallic may be used in offices.

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**INSTALLING LIGHTING FIXTURES**

a. Lighting fixtures shall be installed (according to the fixture schedule) complete with lamps. The heights of mounting shall be as specified on the drawings.

b. Fixtures shall be securely mounted by (an approved fastening method). (Assembly of Hanford Standard D-20-120). A fixture stud shall be used where heavy fixtures or fluorescent fixtures are hung from an outlet box. The box cover fastening screws shall not be used to support these fixtures.

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**INSTALLING STORAGE BATTERIES**

a. Storage battery installations shall be installed according to Article 480 of the National Electrical Code.

b. Wiring for main battery leads shall be colored red, positive and black, negative. Wire and terminals shall be acid resistant.

c. Lighting fixtures (over batteries) (in battery room) shall be vapor tight and hung at least two feet below the ceiling.
INSTALLING FIRE ALARM, COMMUNICATION, AND EVACUATION ALARM SYSTEMS

a. Except as specified in this Section, wiring methods for the fire alarm, communication and evacuation alarm systems are the same as for the other electrical systems covered in these specifications.

b. All splices in alarm systems shall be made mechanically strong and soldered. Single conductors in interior alarm systems shall not be smaller than No. 14 AWG stranded.

c. Fire alarm loop detector circuits shall be color coded and the same color shall be maintained throughout each circuit. Each wire of a detector circuit shall be tagged or labeled at each detector head and at the test panel. Both ends of the loop circuit shall terminate at the test panel.

d. The panelboard breaker supplying 115 volts, a-c to the fire alarm supervisory panel shall be fitted with a suitable guard requiring the removal of a screw to open. The supply breaker shall be painted with red enamel.

e. The auxiliary fire alarm relay panel enclosure(s) shall be painted with red enamel, with "F.A." in one inch high letters painted in white in a prominent place.

f. All fire alarm junction and pull box covers shall be painted with red enamel.

INSPECTION AND TESTING

GENERAL

a. All electrical equipment and wiring installed under these specifications shall be inspected and tested by the Contractor before any attempt is made to operate the equipment. Resistance, current and voltage measurements may be made as the work progresses. The Contractor shall maintain a systematic record by using a schedule or chart of all the tests and measurements. Space shall be provided to record readings, dates, and witnesses. All tests shall be witnessed by the Commission.

b. The Contractor shall correct, to the satisfaction of the Commission, all abnormal or incorrect conditions as determined by the following test and inspection procedure.

MOTORS AND GENERATORS

a. All safety hazards to men and machinery shall be corrected. Frames of motors and generators shall be grounded.

b. Voltage, frequency and number of phases of power supply shall correspond with those required for the machine.

c. The electrical connections shall be checked for tightness and proper insulation.
d. Leads to motors and generators and power wiring shall be checked for proper numbering and color coding in accordance with drawings and specifications.

e. Bearings shall be inspected for proper lubrication.

f. The shaft end play and freedom of rotation shall be checked by hand where practical.

g. Belts shall be checked for the correct tension.

h. The voltage, current and speed (where speed is an important function) under normal operating load shall be measured and recorded.

i. Machines of ______ horsepower and over shall be operated under normal load for a 6 hour heat run. The bearing and winding temperatures shall be measured and recorded. Any unusual noises or vibration shall be observed and corrected before proceeding with the running test.

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**WIRING SYSTEMS**

a. All conduits and devices shall be checked for secure mounting and proper attachment.

b. Conduits, junction boxes and raceways shall be checked for loose or missing covers.

c. Conduit connections shall be checked for tightness.

d. Panels shall be checked for tightness of connections, filling of all open knock-out holes, security of mounting, mechanical damage, identification of panel and circuits therein, cleanliness, and fuse size or overload protective device settings.

e. Circuit numbers shall be checked for conformance with the drawings.

f. All wiring connections shall be checked for proper installation.

g. The proper color coding for all wire and cable shall be verified. All insulated ground conductors shall be checked for green color identification.

h. Plugs and receptacles shall be checked for correct wiring and polarity.

i. All wiring and cable, rated 600 volts or less, and used for services, power feeders, and branch circuits, shall be tested phase to phase and phase to ground with a 500 volt megger. Tests shall be in accordance with the instrument manufacturer's instructions. Any device not capable of withstanding the voltage and current of a megger test (such as microphones, recording and indicating instruments, relays, and lamps) shall be disconnected or by-passed before the test is made. To prevent damage to the wiring under test and to the electrical devices left in place during the test, the maximum voltage output of the megger to be used with each class of insulation shall be as follows:
VOLTAGE OUTPUT OF MEGGER VOLTAGE RATING OF EQUIPMENT
AND WIRING TO BE TESTED
100 and 250 volts Up to 100 volts
400 volts Telephone cable
500 volts 100 to 600 volts

It is permissible to test the entire system or any part of a system including feeder cables, etc., provided the observed minimum insulation resistance is equal to or greater than the values specified in Section 110-19 of the National Electrical Code for the smallest size of wire included in the system or part under test. If such readings are low, the system must be separated until the part causing the low reading is determined and corrected.

LIGHTING SYSTEMS

a. An inspection shall be made to determine that panel interiors are clean, wiring has been properly supported, breakers are of correct rating as shown on the drawings, and that circuit directories completely identify the circuits.

b. An inspection shall be made to insure that all lighting fixtures are properly mounted, equipped with correct size of lamps or tubes, clean and in satisfactory operating condition.

MOTOR CONTROL CENTERS AND STARTERS

a. Each cubicle shall be checked for proper nameplate identification.

b. Equipment and devices in control center cubicles shall be checked with the drawings and schedules to assure that they are correctly mounted and wired, and installed in the correct compartment. The size and rating of breakers, fuses and overload heaters shall be verified.

c. Wire tag numbers, terminal strip markers and wiring shall be checked with the drawings. Wiring shall be checked for standard color coding of phases.

d. The installation of arc-confining baffles or barriers between compartments and devices where provided in control centers shall be checked.

e. All vertical and horizontal bus supports and insulator bolts shall be checked for tightness. All connections, bus to bus, bus to lugs, and bus to stabs shall be inspected to determine that they are silvered, tight, and corrosion free. Buses shall be checked for proper bus phase arrangement as called for in these specifications.

f. Each unit assembly in the control center shall be removed and checked for horizontal and vertical alignment of units and guides, and alignment of stabs with busses. There shall be no tendency to
twist or turn out of position or fit loosely. The unit stabs shall make contact automatically with insertion of unit and disconnect automatically with removal of unit.

g. Door fit and door handle interlocking features shall be checked to assure that door cannot be opened when unit it houses is energized.

h. All breaker, switch, and starter mechanisms shall be checked to see that nuts and bolts are in place and tight, that no pins or keys have worked out of place and that all cotter pins have sufficient spread. Operating rods and moving parts shall not bind and shall be in proper working order.

i. Motor starters shall be operated several times to check for bindfree operation of moving parts, proper contact area and pressure of main and auxiliary contacts, and correct operating coil voltage.

j. Control transformers shall be checked for proper voltage ratio. Fuses for the transformers shall be removed and checked for correct size and condition. All connections and mounting bolts shall be tight.

k. Pilot lights shall be checked to assure proper indication of motor operation. Push buttons shall be checked for connections and operability.

l. Insulation tests shall be made before energizing the control center by resistance measurement of all buses, internal cabling, breakers and starters to ground.

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TRANSFORMERS

a. The condition of high and low voltage bushings shall be checked for freedom from damage and cleanliness.

b. The condition of high voltage (stress cone) (connection) and low voltage bus connections shall be checked.

c. (Oil gages) and (thermometers) shall be checked for damage, tightness, and proper indication.

d. The oil level shall be checked and calculated for 25°C.

e. The case and fittings shall be inspected for oil leaks.

f. The breather shall be checked for obstructions.

g. The relief diaphragm shall be checked for operation.

h. The tank ground shall be checked for continuity and tightness of connections.

i. A sample of oil taken at the bottom of the case shall be checked for dielectric strength.
j. The insulation resistance to ground of primary and secondary windings shall be measured.

k. Connections for proper voltage, phasing and polarity shall be checked.

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**SWITCHGEAR**

a. The switchgear, auxiliaries and conduits shall be checked for workmanship and general appearance. Any external factors such as moisture, chemicals, dust and oil that are detrimental to the switchgear shall be removed.

b. All breakers and compartments shall be checked for identification according to the drawings.

c. Switchgear shall be checked for missing covers, loose or missing parts, dirt on relays, meters, or other devices. Doors and locks shall be checked for proper fit.

d. The overcurrent tripping devices and the trip latches shall be inspected for freedom of movement.

e. All breakers shall operate satisfactorily at the control voltage.

f. All breakers shall be racked out from the enclosures and checked for proper functioning of the mechanism. Where breakers are interchangeable, all possible combinations shall be checked for fit and operation. All readily accessible parts shall be checked for proper insulation from live parts of the breaker. The mechanical interlocks shall be checked for positive trip before a breaker can be moved from the connect position, and when approaching the connect position from the disconnect position.

g. The door shall be checked to ensure that it (can) (cannot) be opened when the breaker is closed without tripping the breaker. Check provisions for locking the breaker in the trip position and locking of the lift mechanism or door.

h. All buses, incoming lines, feeders, and tie connectors shall be checked for phase sequence, identity and proper color coding.

i. Each control switch shall be checked for operation and provision for locking in the trip position. Operation of red and green lights shall be checked for correct operation in the respective positions of the breakers.

j. All relays shall be tested and adjusted according to the manufacturer's instructions.

k. Voltmeters and ammeters shall be checked for proper indication on each phase by operating transfer switch.

l. Key interlocked breakers shall be checked for operation of the lock system. The number of keys specified for each interlock system shall be checked.
m. Surfaces shall be checked for scratches.

FIRE ALARM, COMMUNICATIONS, AND EVACUATION SYSTEMS

a. The continuity of each of the fire alarm loop circuits shall be checked.

b. Each fire detector loop circuit shall be checked for color coding and that the same color is maintained throughout each circuit.

c. The resistance of each loop circuit shall be checked. The resistance shall not exceed 30 ohms.

d. The fire alarm test switch shall be operated to determine that the alarm sounds.

e. Evacuation alarm circuits from the building terminal box shall be checked. A temporary power source shall be applied to the evacuation circuit to determine that alarms will sound.

f. All circuits shall be checked for grounds.

g. Fire alarm circuits shall be checked for broken line operation.

h. Each box shall be operated and checked for proper timing and coding as determined by the Commission.

i. Each auxiliary box shall be checked for operation of master box.

j. Each fire detector head shall be checked for operation.

k. Batteries and battery charger shall be checked for proper operation and charging rate.

l. All auxiliary transmitters and circuit openers shall be checked for proper operation.

m. Opening of fan circuits upon activation of a fire alarm shall be checked. Circuits shall remain open until manually reset.

n. Each of the sound powered telephone jack positions from the building terminal point to the telephone jacks shall be checked for continuity.
DG-210-E

DESIGN GUIDE

for

HIGH VOLTAGE CABLE SPLICES AND TERMINATIONS
High quality workmanship and the use of the correct materials are of the utmost importance for high-voltage cable splices and terminations if mechanical and electrical failures are to be avoided. Particular attention must be given to securing solid and low resistance connections, uniform voltage stress, adequate insulation thickness, freedom from voids, chemical compatibility between materials, and vapor proof seals.

Since the original HAPO Facilities were built in 1944, there have been many alterations and additions to the plant involving the installation of insulated cable. The type of cable has been determined by availability and the designer's judgment. Because of increased power loads, existing cables have been paralleled with new feeder cables and bus ties to obtain added capacity. It has sometimes been necessary to splice two different types of cables in order to extend or relocate feeders. Of the many types now installed, the three most common are varnished cambric insulated (sometimes lead sheathed), natural rubber insulated, and synthetic rubber insulated. The Design Guide will be limited to a discussion of these three types.

A great variety of insulating materials, cleaning solvents, solder fluxes, paints, and varnishes are available. However, deterioration of a splice can occur over a period of time due to chemical actions if these materials are used indiscriminately. Some cable manufacturers are more specific than others as to the splicing materials to be used. Regardless of the manufacturer's interest, the splice is the responsibility of the purchaser; therefore, specific details should be included by the designer for each splice and terminal in the design of high-voltage systems.

1. General Discussion

The design of any high-voltage (2 to 15 KV) cable installation should include detailed instructions for making the terminations and splices as well as specifying the materials to be used. This is particularly important when splicing or terminating dissimilar cables.
In the past, splices and terminations of cables operating at voltages above 600 were made in compound boxes or potheads. The two basic reasons for this practice was (1) to prevent moisture from entering the cable and, (2) in the case of unshielded three-conductor cables, to exclude all air from the crotch and prevent breakdown due to the high concentration of voltage stress at that point.

With the use of rubber and rubber-like insulations and shielding tapes, the pothead termination is being replaced by a tape type termination. The exclusion of moisture is no problem with rubber insulation and shielding tapes prevent high stress concentrations. Of course, where the termination is in a location exposed to corrosive or conducting gases, the pothead termination is still recommended.

Whenever air is subjected to high voltage stress, ionization of oxygen in the air forms ozone. At the same time energy in the form of light is emitted and this phenomenon is termed corona. The degree of voltage stress required for ionization is dependent upon the shape of the conductor as well as operating potential. Corona can occur on a bare conductor operating at voltages as low as 2 KV regardless of the air space to ground, or the return conductor. Although the ionization itself does not affect rubber insulation, ozone attacks the rubber causing it to harden and crack and eventually to break down entirely. For this reason, air pockets between the conductor and the rubber or within the rubber cannot be tolerated.

High voltage between conductors can cause corona even at the outer surface of the insulation if the voltage stress is sufficiently great. By applying a conducting shield, maintained at ground potential, over the insulation, the dielectric field is confined to the insulation and the voltage stress in the air is eliminated. The shielding also distributes the voltage stress in the insulation uniformly along the cable. See IPCEA Standard S-19-81, Part 5 for recommended shielding practice.

Where a cable is terminated or spliced, the shielding is broken and the dielectric field is no longer confined to the insulation but distributes itself between the conductor and ground. It is, therefore, apparent that a high concentration of stress will exist where the shielding ends. This concentration can be reduced by the use of a stress relief cone.
The stress cone is made by increasing the insulation thickness at the end of the shield. Enough additional insulation is applied to make the total insulation about twice the normal thickness. From the high point the additional insulation is tapered off in both directions. The shield is then terminated at the high point, and a resultant reduction of stress concentration is attained.

High voltage cable to be used is specified in HAPO Standard HWS-8006-S. The insulation is of butyl rubber with polychloroprene sheath and made according to IPCEA Specifications Appendices O and K. For systems operating at more than 3 KV, 3-ph, line-to-line, cable with a metallic shielding tape applied beneath the polychloroprene sheath is recommended by IPCEA. In splicing or terminating this cable, the recommendation for methods and material should be obtained from the manufacturer. Also, references 3 and 4 at the end of this Design Guide contain detailed instructions for making splices and terminations and are recommended as a guide for design and field use.

Appendix I of this Design Guide contains some general instructions that can be used as a supplement to instructions from the cable manufacturer. Especially the statements of caution should be noted by the splicer.

2. Rubber and Rubber-Like Insulated Cable Splicing

The splicing sleeve or connector must be smooth and as nearly circular in cross-section as possible to uniformly distribute the lines of voltage stress in the insulation. All sharp points should be filed off and indentations filled with solder. If the connection is very irregular such as two lugs bolted together, a metallic foil, metallic-braid or semi-conducting tape may be used to round out the connection. The foil or braid must not cover any insulation.

In applying the insulation tape over the bared conductor and sleeve, voids must not be permitted next to the conductor or between layers of tape. This is to prevent corona and the resultant ozone breakdown of the insulation.

Natural rubber tape is only semi-vulcanized when applied. Pressure and heat complete the vulcanizing process, and the compound becomes a homogeneous mass. Rubber cement is used to seal the compound to the factory insulation. As the rubber tape is put on, rolling with a heated spool (about 140 F) will help push out the air and vulcanize the tape. Butyl compound tape is almost fully vulcanized when applied and it too becomes a homogeneous mass with time and pressure. The tapes should be kept free of dirt and moisture.
Rubber tape will bond by self-curing which takes place because of pressure between layers. When rubber tapes are stored for extended periods at elevated temperatures, they tend to cure on the roll. This may seriously affect the bonding properties of the tape. Therefore, the tape must not be stored over six months if temperatures exceed 80°F. If temperatures are below 80°F, the tape may be stored up to a year.

Various cable manufacturers have been concerned about the use of oil-based rubber tape when splicing cables of butyl insulation, and vice-versa. Therefore, it is recommended that the splicing tape be of the same compound as the cable insulation. In the event it is necessary to splice an oil-based rubber insulated cable to a butyl insulated cable, it is recommended that butyl tape be used. If an oil-based rubber tape is used, the vegetable oils blended therein may have an adverse affect on the butyl compound. (See Reference 2 on page 7).

Rubber cement is used to obtain a bond between the splicing compound and the factory applied insulation. The cement used should be compatible with the splicing compound and as recommended by the tape manufacturer.

Solvents are used to remove wax finishes from the sheath, to remove particles of semi-conducting tape from insulation, and to remove excess soldering flux. Stoddards Solvent, naptha, Solvasol No. 5, white gasoline, and benzine are approved for use. Excess solvent should be wiped from the insulation immediately, and sufficient time must be allowed for the remaining solvent to evaporate before proceeding with the work.

For soldering splicing sleeves, a 60-40 lead-tin solder in accordance with Alloy Grade 40-A of ASTM Specification B-32-49 is approved and should be used with a styrene flux. Acid fluxes must not be used because they deteriorate the insulation. Excess solder should be filed off but should not be removed to the extent that the copper is left untinned.

3. **Varnished Cambric Insulated Cable Splicing**

Varnished-cambric insulation consists of an unsized cotton cloth impregnated with a clear varnish or a black asphaltic base varnish. The varnish is of vegetable oils blended with resinous or asphaltic materials.

The same factors concerning the splicing sleeve, solder and solvents apply to varnished-cambric insulation as to rubber insulation. Details in removing and handling the lead sheath, reinforcing the splice, applying the shielding tape, and providing the moisture seal is done according to the manufacturer's instructions or information contained in General Electric Catalog, Section CM658.
When splicing a varnished-cambric insulated cable to a rubber insulated cable, proceed as if splicing two rubber insulated cables, with the following exceptions:

1. Provide a barrier of solder between the butted ends of the cables within the splicing sleeve to prevent any possibility of oil or varnish in the strands of the varnished-cambric cable migrating into the rubber cable. Compression splicing sleeves will not be permitted for these splices.

2. Strip off the varnished-cambric insulation in steps as follows: The steps should be made by cutting the cloth tapes, exercising care to avoid cutting through tapes that will remain on the conductor. The first step adjacent to the conductor should be 1/32 inch (31 mils or two layers) high and 1/2 inch long. The remaining steps (about 3) should be of equal height and 3/4 inch long. Cotton yarn should be bound into the stepped corners of the insulation. In passing from one step to the other bind down the tape ends with a turn of yarn. Excessive yarn should be avoided. One turn in the first step and two turns in the other steps is sufficient. Start the binding in the corner formed by the conductor and the connector. Drive moisture from the yarn and varnished-cambric tape with heat; however, excessive heat must not be applied and a radiant source is recommended.

3. Provide an oil or varnish seal over the varnished cambric by wrapping two half-lapped layers of varnished-silk tape (G. E. No. 590 or equal) over the varnished-cambric from the connector to, but not over, the semi-conducting or shielding tape. Start wrapping from the connector.

Instead of a varnished-silk tape covering, a coat of red Glyptal* (or equal) resin may be applied. Let the Glyptal dry thoroughly before proceeding.

4. Apply rubber cement over the varnished-silk or Glyptal, conductor, connector, and rubber insulation. Let solvent evaporate until the cement is tacky and apply the rubber tape insulation as for a rubber-to-rubber splice.

* General Electric Company trade name
5. Continue with Scotch #33 Electrical Tape** or equal, shielding tape, ground connection, additional rubber tape, and final layers of Scotch #33 tape as per instructions for rubber insulated splices.

6. If the varnished-cambric cable has a lead sheath, bell out the sheath and finish smooth. Clean the lead sheath with solvent and extend the final layers of Scotch tape on to the lead for five or six inches.

7. Paint entire splice with Scotch-Kote** or equal.

4. Terminations

In terminating shielded cables, the stress cones should be built up according to the cable manufacturer's directions. However, a pressure type lug must be installed instead of sweating a solder lug onto the cable. The lug must be of a type that will allow sealing the end of the conductor against the entrance of moisture. Insulating tape should then be applied between the connector and the cable in a manner to provide a moisture proof seal. The factory insulation of the cable should be penciled, or stepped in the case of varnished cambric, the same as for a splice. Two layers of half lapped Scotch #33 tape or equal from the lug to 2 inches beyond the tape forming the stress cone should then be applied. Tape should be wrapped in a manner to shed water.

5. Making Connections to the Bus or Switchgear

When the terminating lugs are bolted to the bus, the edges of the bolts, nuts, and bus bars form points of concentrated stress lines as well as form pockets and corners for air voids. A wrapping of metallic braid will round off these edges and provide a uniform stress pattern around the connection. The small voids left under the metallic braid are not significant because the boundary of the conductor is now defined by the braid. If metallic braid is not used, a sealing compound such as Volseal* or Duxseal* or equal may be used to fill up the voids. Use only enough compound to fill the voids. The exposed metal is then insulated with several layers of half lapped Scotch #33 Electrical tape or equal, applied smoothly but without tension (13 layers for 13.8 KV bus, 5 layers for 4.16 KV bus, 3 layers for 2.4 KV bus).

** Minnesota Mining & Manufacturing Company trade name
* Johns-Manville trade name
6. References

Information for this Design Guide has been taken in part from the following references:


4. Simplex Wire and Cable Company - Important Instructions for Splicing and Terminating Shielding Anhydrex Rubber-Jacketed Cable.

Supplementary Instructions
Cable Splicing and Terminating
Shielded-Ozone Resistant Rubber Insulation - - Polychloroprene Jacketed Cable

To supplement the instructions supplied by the cable manufacturer the following instructions and cautions should be observed by the splicer.

1. When removing the jacket, do not ring cut the jacket because of the danger of cutting the metallic shielding and insulation. Hold the knife at an angle and peel off the jacket toward the end of cable.

2. As each layer is removed and cut off at the prescribed distance, be sure the material underneath is not cut or nicked. The metallic-shield tape end should be tacked in place with solder. Where the shielding tape is removed, all semiconducting tape underneath must be removed.

3. When removing the rubber insulation to expose the conductor, pencil (or taper) the insulation smoothly for the distance called for or about 1-1/2 times the insulation thickness. Use sandpaper to smooth up the taper. Emery paper contains particles of conducting material and must not be used.

4. A solvent may be used to remove wax finishes on the jacket and compounds on the semi-conducting tapes. However, the solvent should be used sparingly and all excess wiped off. Allow sufficient time for solvent to evaporate before covering with tape.

5. When soldering the splicing sleeve to the butted conductors, the splicer must prevent overheating the copper and damaging the insulation. If damp cloths are used, drive off moisture by applying radiant heat.

6. The copper conductors of the cable are tinned. If the tin plate is scraped off to expose bare copper when removing the insulation or excess solder from the splicing sleeve, re-tin the exposed position.

7. Use stearine flux for soldering. Acid fluxes will damage the insulation. In the event a compression type sleeve is used, the indents must be filled with solder so the connector will have a smooth evenly-rounded surface. Use a tinned copper sleeve. If the conducting surface is extremely irregular a layer of tinned metallic braid or foil should be applied but do not cover any insulation with the braid or foil.
8. The work must be kept clean and dry at all times.

9. Before applying the rubber insulating tape, cover the exposed insulation, and splicing sleeve with rubber cement. Do not cover the semi-conducting tape under the metallic shield with cement. Let the solvent in the cement evaporate until it becomes tacky. Do not apply cement between layers or over the insulating tape.

10. In applying the rubber tape, there must not be any air voids or foreign matter of any kind under the tape or between layers. While wrapping, stretch the 3/4" wide tape until it narrows down to 1/2". Even tension should be used to give a uniform thickness and density to each layer. Do not apply insulating tape over the semi-conductor or shielding tape.

11. Wrap a layer of semi-conducting tape between the insulating tape and the shielding tape and in intimate contact with the insulating tape. The semi-conducting tape must end at the high point of the taper on a stress cone. If semi-conducting tape is not furnished in the splice kit, Scotch #33 Electrical Tape or equal can be used. Do not stretch the Scotch tape but apply only enough tension to lay the tape on smoothly and without wrinkles. Copper mesh shielding tape must, of course, be used on all stress cones.

12. Cables insulated with butyl-based rubber compound must be spliced and terminated with butyl-based tape. Natural and GR-S synthetic rubber compound insulated cables must be spliced and terminated with oil-based rubber tape. Butyl-based tape should be used if an oil-based rubber insulated cable is spliced to a butyl-based rubber insulated cable.

13. In splicing, the shield tape must have continuous conduction over the splice. The shield tape should be applied in two pieces starting application of each from the center of the splice. In this way the tape is applied down the taper. Tack solder the shield tape ends to the shield of the cables, and tack solder each successive layer of shield tape in at least three places per turn.

14. If an irregular terminating lug is used, a filler compound such as Volseal or Duxseal or equal may be used sparingly.
DG-300-W

GUIDE FOR

WELDING MISCELLANEOUS METALS AND ALLOYS
# GUIDE FOR WELDING MISCELLANEOUS METALS AND ALLOYS

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<tr>
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PURPOSE

The purpose of this Guide is to assist in the preparation of drawings and specifications for the welding of miscellaneous metals and alloys, and to bring to attention the conditions or situations which should be considered and evaluated. The recommended practices are those which have been found to be most satisfactory for use at Hanford Atomic Products Operation.

INSTRUCTION FOR USE

This Guide is not to be used as a substitute for construction or procurement specifications and is not to be issued to vendors.

It shall not be used as a substitute for consulting specific literature which sets forth the detailed characteristics of the material being considered as part of a weldment to be fabricated.

The information which applies to the specific metallic material is noted in the section relating to that particular classification of welding information. The general arrangement is similar to the Hanford Standard Welding Specifications so that specifications written from this Guide will be in similar form. Arrangement is by sections in such a manner that the information which is applicable to several or all of the metallic material families listed in Section 1 "SCOPE" has not been duplicated.

The designer should be governed in his choice of alternatives by current labor and procurement conditions or other factors peculiar to the specific job requirements.

GENERAL

Suggestions for additions or corrections should be addressed to the Secretary, Engineering Standards Council.

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GUIDE FOR

WELDING MISCELLANEOUS METALS AND ALLOYS

1. SCOPE

This Guide for Welding Miscellaneous Metals and Alloys pertains only to certain welding and related fabrication considerations of the following metallic material families:

- Cast irons
- Clad metals and alloys
- Copper and copper alloys
- Die cast alloys
- Dissimilar metals and alloys (where one metal or alloy is welded to another - filler metal excepted)
- High temperature alloys
- Lead and lead alloys
- Low and high-alloy steels
- Magnesium and magnesium alloys
- Metals and alloys which require inert gas shielding of the heated area, such as tantalum, titanium, molybdenum and zirconium
- Nickel and nickel alloys (not stainless steels)
- Wrought iron

This Guide does not cover the welding of pressure vessels which should be designed and fabricated in accordance with the requirements of the latest edition of Section VIII, ASME BOILER AND PRESSURE VESSEL CODE including any subsequent addenda.

Nearly all of the materials listed in Section 1 "SCOPE" have a complex metallurgical behavior; the joint efficiencies of welds are sometimes low and welding requires special techniques and procedures. A HAPO welding engineer should be consulted when special welding details are being considered by the designer.

2. HEALTH HAZARDS

The potential hazard existing when welding materials that emit fumes and dust which are toxic should not be overlooked. The most common metal vapors which may be encountered are those emitted by lead, cadmium,
beryllium, magnesium, zinc and copper. Fluorine-bearing fluxes emit toxic fumes when heated and adequate exhaust devices must be used. Also, if a chlorinated hydrocarbon, such as carbon tetrachloride, trichlorethylene, etc., is used to degrease the work, the fluid should be permitted to evaporate or be wiped from the work before the welding operation is started. Arc welding should never be done in any location near fumes of those solvents as they will dissociate in the light of the arc to form a poisonous gas, phosgene.

3. QUALIFICATION OF WELDERS

Because of the specialized nature of most of the metallic material families listed, it will generally be necessary to require special welder qualification tests. The ability of the welder or welding operator should be proved by requiring that he weld a joint or series of joints which will demonstrate his relative ability with regard to the fabrication to be done. These tests should take into consideration the special characteristics of the material to be welded. They should also be realistic in relation to the actual fabrication to be done. Ordinarily, the actual welding methods to be used for the fabrication are left to the discretion of the fabricator, subject to review and approval by the purchaser.

When the designer believes that the nature of the work to be done is of sufficient importance to warrant qualification of the welding operator, he should enlist the assistance of a HAPO welding engineer to determine what tests should be taken by the operator to be tested.

4. MATERIAL IDENTIFICATION

Materials used in the fabrication should be certified by the fabricator as to the correct analyses and tempers. This point is extremely important for materials falling under the classification of "MISCELLANEOUS METALS AND ALLOYS" listed under Section 1 "SCOPE". A slight change in chemical composition or physical condition of the material in certain cases may mean the difference between a weldable material and one which can not be joined by welding. References included under Section 1 "BIBLIOGRAPHY" will be of assistance in choosing materials that appear under Section 1 "SCOPE" and which are weldable by certain processes.

5. FILLER MATERIAL

GENERAL

When filler material is required for the joint being welded, the proper filler material must be selected and specified. The various metallic material families and the filler materials which have been used to join them are listed in the following, together with the welding process by
which they have been applied. Special applications may require special filler material. As an example: in corrosive environments filler material should be checked for compatibility with the base material.

5.1 CAST IRONS

Gray cast iron may be welded with the oxy-acetylene process or inert-gas-shielded tungsten-arc process using core cast iron filler rods having sufficient silicon content to give the weld deposit adequate machinability.

The oxy-acetylene process is the superior method and the one which will insure greatest possibility of success with the operation. Preheating and postheating assist in avoiding cracks in the weld or base material during and after welding. Slow cooling under asbestos blanket or lime also assists in avoiding cracks. When such special cast irons, as Ductile Iron, malleable cast iron, Duriron, Ni-Resist, Gun Iron, and the like arc to be welded, the filler material to be used for joining or surfacing them must be given special consideration. Also, special welding techniques and procedures are required for most of these.

The following filler materials have been used successfully under various welding conditions for joining or surfacing the cast irons with the shielded metal-arc:

- Electrodes having a nickel core with a copper sheath and flux coating
- Electrodes having a nickel-copper core with a mild steel sheath and flux coating
- Electrodes having copper core with a mild steel sheath and flux coating
- Nickel electrodes having a flux coating
- Phosphor bronze electrodes having a flux coating
- Cast iron electrodes having a flux coating
- Mild steel electrodes having a special flux coating

Special welding techniques and procedures must be used to insure success of the welding operation and to avoid cracking of the base material in the heat-affected zone. It may be necessary to use light peening as a control on distortion and shrinkage as the welding operation progresses.
5.2 CLAD METALS AND ALLOYS

Special welding procedures are required for joining clad metals and alloys. When such materials are to be welded, if at all possible, it is customary to weld the cladding material first. The cladding material should be welded with a filler rod which will give the same corrosion resistance as the cladding material in order that the weldment will give the required service. The base material should be welded with the process and filler material best suited for the particular form, analysis and thickness of the material involved. The cladding material should be joined with the shielded metal-arc, the inert-gas-shielded tungsten-arc or the inert-gas-shielded metal-arc processes. The welding procedure and application should be such that the cladding material in the weld will not be contaminated or diluted with base material or filler material used to join the base material.

5.3 COPPER AND COPPER ALLOYS

Copper and copper alloys are classified according to the following general headings. Their relative weldability is also shown.

<table>
<thead>
<tr>
<th>Copper-zinc alloys (brasses)</th>
<th>Oxy-acetylene</th>
<th>Carbon Arc</th>
<th>Shielded Metal-Arc</th>
<th>Inert-Gas-Shielded</th>
<th>Tungsten-Arc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low brasses (Cu 80 to 95 percent, Zn 5 to 20 percent)</td>
<td>Good</td>
<td>Fair</td>
<td>Poor</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>High brasses (Cu 55 to 80 percent, Zn 20 to 45 percent)</td>
<td>Good</td>
<td>Fair</td>
<td>Poor</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Alloy brasses</td>
<td>Fair to poor for all processes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Copper-silicon alloy (silicon bronze) Readily weldable by any of the common methods

Copper-tin alloys (phosphor bronzes) Oxy-acetylene Fair
Shielded Metal-Arc Good
Inert-Gas-Shielded Good
Tungsten-Arc

Copper-aluminum alloys (aluminum bronzes) Oxy-acetylene Fair
Shielded Metal-Arc Good
Inert-Gas-Shielded Good
Tungsten-Arc

Copper-nickel alloys Oxy-acetylene Good
Carbon Arc Fair
Shielded Metal-Arc Good
Inert-Gas-Shielded Good
Tungsten-Arc

Nickel-silver alloys Oxy-acetylene Good
Carbon Arc Fair
Shielded Metal-Arc Fair to Good
Inert-Gas-Shielded Good
Tungsten-Arc

Copper-beryllium alloys Cannot be joined by oxy-acetylene welding
Carbon Arc Good
Inert-Gas-Shielded Good
Tungsten-Arc

The following metals and alloys have been successfully joined by the filler materials listed opposite them. The notations in parentheses indicate the ASTM classification or anticipated classification.

Electrodes for shielded metal-arc welding

<table>
<thead>
<tr>
<th>Materials</th>
<th>Filler Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen-bearing coppers, oxygen-free coppers</td>
<td>Deoxidized-copper (ECu)</td>
</tr>
<tr>
<td>Copper, bronze, brass</td>
<td>Phosphor-bronze A (ECuSn-A)</td>
</tr>
<tr>
<td>Copper, bronze, brass</td>
<td>Phosphor-bronze C (ECuSn-C)</td>
</tr>
<tr>
<td></td>
<td>Used for same work as &quot;A&quot; above, but gives higher strength.</td>
</tr>
</tbody>
</table>

DG-300-W
### Electrodes for shielded metal-arc welding (Cont.)

#### Materials

Copper-nickel alloys  
Copper-silicon alloys  
Aluminum-bronze sheet, manganese bronze, castings, dissimilar metals  
Aluminum-bronze  
Surfacing for wear resistance  
Surfacing but harder than ECuAl-C  
Surfacing but harder than ECuAl-D

#### Filler Materials

Copper-nickel (ECuNi)  
Copper-silicon (ECuSi)  
Aluminum-bronze (ECuAl-A)  
Aluminum-bronze (ECuAl-B)  
Aluminum-bronze (ECuAl-C)  
Aluminum-bronze (ECuAl-D)  
Aluminum-bronze (ECuAl-E)

#### Bare Welding Rods

Oxygen-free copper  
Oxygen-free coppers, copper-silicon alloys  
Phosphor-bronze, copper-tin-zinc castings  
Phosphor-bronze plates, copper-tin zinc castings  
Copper-nickel sheet and plate  
Brass, braze-welding of steel, cast iron malleable iron, copper, bronze and nickel alloys  
Braze welding of steel and cast iron, Building up bearing surfaces  
Braze welding of steel and cast iron, Building up bearing surfaces  
Bronze welding of steel and cast iron for color match

Copper (GCu)  
Copper-silicon (GCuSi)  
Phosphor-bronze A (GCuSn-A)  
Phosphor-bronze D (GCuSn-D)  
Used for same purpose as "A" above, but has easier welding characteristics because of lower melting temperature  
Copper-nickel (GCuNi)  
Naval bronze (GCuZn-A)  
Manganese bronze (GCuZn-B)  
Low fuming bronze (GCuZn-C)  
application similar to GCuZn-B  
Nickel-bronze (GCuZn-D)

---

DG-300-W
It may be necessary to preheat heavy sections to assist the welding operation.

Repair welding may be impossible on certain copper castings owing to the tendency of some elements in the base material to segregate.

5.4 ZINC BASE ALLOY DIE CASTINGS

Any of the commercially manufactured filler rods for these materials are satisfactory. However, welding is seldom done except for repair purposes.

5.5 DISSIMILAR METALS AND ALLOYS (WHERE ONE METAL OR ALLOY IS WELDED TO ANOTHER - FILLER METAL EXCEPTED)

New and different combinations of metals and alloys are continually being joined by welding. In such cases it is of great importance that the designer know which filler material should be used with which welding process in order that the desired physical or other properties may be attained in the joint. It is somewhat difficult to predict the composition, structure and mechanical properties of the weld when dissimilar metals or alloys are to be joined. However, the following information indicates which filler materials have been used to successfully join the indicated base metals or alloys:
### Filler Metal for Shielded Metal-Arc Welding of Dissimilar Metals

<table>
<thead>
<tr>
<th></th>
<th>Nickel</th>
<th>&quot;L&quot; Nickel</th>
<th>Monel</th>
<th>&quot;K&quot; Monel</th>
<th>Inconel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nickel</td>
<td>1</td>
<td>1</td>
<td>0,1</td>
<td>0,1,4</td>
<td>1,2,3</td>
</tr>
<tr>
<td>&quot;L&quot; Nickel</td>
<td>1</td>
<td>1</td>
<td>0,1</td>
<td>0,1,4</td>
<td>1,2,3</td>
</tr>
<tr>
<td>Monel</td>
<td>0,1</td>
<td>0,1</td>
<td>0</td>
<td>0,4</td>
<td>1,0,2</td>
</tr>
<tr>
<td>&quot;K&quot; Monel</td>
<td>0,4,1</td>
<td>0,4,1</td>
<td>0,4</td>
<td>4</td>
<td>1,0,4</td>
</tr>
<tr>
<td>Inconel</td>
<td>1,2,3</td>
<td>1,2,3</td>
<td>1,0,2</td>
<td>1,0,4</td>
<td>2,3</td>
</tr>
<tr>
<td>Carbon Steel</td>
<td>1,0,2</td>
<td>1,0,2</td>
<td>2,5,1</td>
<td>2,5,1</td>
<td>3,2</td>
</tr>
<tr>
<td>Galvanized Steel</td>
<td>1,0</td>
<td>1,0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Stainless Steels</td>
<td>2,1,8</td>
<td>2,1,8</td>
<td>0,1</td>
<td>0,1</td>
<td>2,3,8</td>
</tr>
</tbody>
</table>

**NOTE:** Recommendations are in the order of preference

**CODE:**

- 0         - Monel electrodes
- 1         - Nickel electrodes
- 2         - Inconel electrodes
- 3         - 80/20 nickel-chromium electrodes
- 4         - "K" Monel electrodes
- 5         - Special Monel electrodes
- 5         - Stainless steel electrodes (Normally of same type as base material)

**Metals or Alloys**

- Nickel to cast iron
- Copper alloys to steel

**Filler Materials**

- Nickel electrodes
- Copper-silicon welding rods
- DG-300-W
**BRONZE ELECTRODE SELECTION AND PREHEAT CHART**

<table>
<thead>
<tr>
<th>Electrode Code No.</th>
<th>Electrode Code No. 1</th>
<th>Electrode Code No. 2</th>
<th>Electrode Code No. 3</th>
<th>Electrode Code No. 4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Copper (Deoxidized)</strong></td>
<td>3G</td>
<td>3G</td>
<td>3G</td>
<td>3G</td>
</tr>
<tr>
<td><strong>Phosphor Bronze (A)</strong></td>
<td>3C</td>
<td>3F</td>
<td>3C</td>
<td>3C</td>
</tr>
<tr>
<td><strong>Phosphor Bronze (C)</strong></td>
<td>3C</td>
<td>3F</td>
<td>3C</td>
<td>3C</td>
</tr>
<tr>
<td><strong>Silicon Bronze</strong></td>
<td>4,3,1A</td>
<td>4,3,1F</td>
<td>4,3,1A</td>
<td>4,3,1A</td>
</tr>
<tr>
<td><strong>Naval (Yellow) Brass</strong></td>
<td>3,1D</td>
<td>3,1F</td>
<td>3,1D</td>
<td>3,1D</td>
</tr>
<tr>
<td><strong>Low Carbon Steel</strong></td>
<td>1B</td>
<td>1F</td>
<td>1</td>
<td>3,1B</td>
</tr>
<tr>
<td><strong>Med. Carbon Steel</strong></td>
<td>1B</td>
<td>1F</td>
<td>1</td>
<td>3,1B</td>
</tr>
<tr>
<td><strong>High Carbon Steel</strong></td>
<td>1D</td>
<td>1F</td>
<td>1D</td>
<td>3,1D</td>
</tr>
<tr>
<td><strong>Cast Iron</strong></td>
<td>1,3C</td>
<td>1,3F</td>
<td>1,3C</td>
<td>1,3C</td>
</tr>
<tr>
<td><strong>Malleable Iron</strong></td>
<td>1,3B</td>
<td>1,3F</td>
<td>1,3B</td>
<td>1,3B</td>
</tr>
<tr>
<td><strong>Stainless Steel</strong></td>
<td>1B</td>
<td>1F</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td><strong>Tool Steel</strong></td>
<td>1F</td>
<td>1F</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td><strong>Manganese Steel</strong></td>
<td>1B</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

**HOW TO USE THE CHART**

Recommended electrode for welding like and dissimilar metals with bronze electrodes is coded by Number. Electrodes are selected according to weldability except in those cases where mechanical properties are considered of more importance.

Recommended preheat and interpass temperature is coded by letters. Preheat and interpass temperature shown for joining dissimilar metals is that recommended for the metal or alloy requiring the highest temperature of the two. Temperatures also vary with the mass and shape of the weldment.

**ELECTRODE CODE NO. 1**

- Air Reduction
- Ampco Metal, Inc.
- Metal & Thermit Corp.

**ELECTRODE CODE NO. 3**

- Air Reduction
- American Agile
- Ampco Metal, Inc.
- Champion
- General Electric
- Hobart
- Holland
- Marquette
- Metal & Thermit Corp.
- Wilson

**PREHEAT AND INTERPASS TEMPERATURE CODE**

- A = - - - - - 150 F
- B = - - - - - 300 F
- C = - - - - - 400 F
- D = - - - - - 500 F
- F = - - - - - 700 F
- G = - - - - - 800 - 1000 F

* or equal
5.6 HIGH TEMPERATURE ALLOYS

When high temperature alloys are used, the service which justifies their use will be such as to require very positive information with regard to specific filler materials and the procedures by which they are applied. When high temperature alloys are used, it will be necessary in each case for the designer to consult a HAPO welding engineer or authorities on the subject unless positive information is at hand relative to the use of the filler material in question for the specific metal or alloy to be welded.

5.7 LEAD AND LEAD ALLOYS

Lead alloys are commercially known as "Corroding", "Chemical", "Acid", "Copper", "Desilverized", "Antimonial", and "Tellurium" leads. When lead or lead alloys are welded, the filler material should be of the same composition as the lead to be welded. Strips of the base material are sometimes used for this purpose if the proper filler rod is not available. Lead and lead alloys are ordinarily welded with the oxy-acetylene or the oxy-hydrogen process. However, the carbon arc and inert-gas-shielded tungsten-arc processes have also been used.

5.8 LOW AND HIGH-ALLOY STEELS

Alloy steels may be considered as low, medium or high-alloy by different users. No rigid classification of low-alloy steels has been accepted, although the figure of eight percent of alloy content has been widely used as the line of demarcation between the low and high-alloy steels. Low-alloy steels owe their inherent properties to the presence of one or more chemical elements in addition to those commonly present in carbon steel. Special consideration must be given these steels when they are welded. They are susceptible to cold-cracking in the heat-affected zone when they are welded with the shielded metal-arc. The low-hydrogen types of electrodes (ASTM Classification EXXX-15 or EXXXX-16) generally give the most successful results. However, it must be determined that the welding design, the joint geometry and the preparation, the welding procedure and the heat treatment (preheat, interpass temperature or post-heat) are proper for the material at hand.

The welding materials for welding high-alloy steels should be designated by a HAPO welding engineer if the material involved does not fall into a definite classification for which HAPO Standards specify the welding materials to be used.

5.9 MAGNESIUM AND MAGNESIUM ALLOYS

Magnesium and its alloys should be welded only with the inert-gas-shielded welding processes. The ASTM magnesium alloys listed below can be welded with the corresponding filler material listed under the heading "Welding Rod."
5.10 METALS AND ALLOYS WHICH REQUIRE INERT GAS SHIELDING OF THE HEATED AREA, SUCH AS TITANIUM, ZIRCONIUM, ETC.

When welding such materials it is customary to use filler material of the same chemical composition as the workpiece. The welding of these materials requires special attention which should include the selection of filler material for the specific application according to the material manufacturer's recommendations. A RAPO welding engineer should be consulted when such materials are to be welded.

5.11 NICKEL AND HIGH-NICKEL ALLOYS

The following nickel and high-nickel alloys are joined with filler material of the same nominal chemical composition as that of the base material to be welded:

- Nickel
- "L" Nickel (Low Carbon)
- Duranickel
- Monel
- "K" Monel
- Inconel
- Inconel X

Other nickel-base heat-resisting alloys

5.12 WROUGHT IRON

The following filler rods may be used successfully for joining wrought iron: Excessive penetration into the base metal should be avoided; otherwise difficulties may be encountered due to inwash of slag from the base metal.
### Shielded Metal-Arc Welding

E60XX series of classifications of ASTM Designation: A233
Tentative Specifications for Mild Steel Arc-Welding Electrodes

### Oxy-Acetylene Welding

GA60 classification of ASTM Designation: A251
Tentative Specifications for Iron and Steel Gas-Welding Rods

#### 6. PROCESSES FOR WELDING MISCELLANEOUS METALS AND ALLOYS

Processes that may be used for joining dissimilar metals and alloys are indicated in Plate 5 "PROCESSES FOR JOINING DISSIMILAR METALS AND ALLOYS"

The following materials may be successfully welded with the process appearing opposite the metallic families listed below:

<table>
<thead>
<tr>
<th>Material</th>
<th>Welding Processes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Metals and alloys which require gas shielding of the heated area, such as titanium and zirconium</td>
<td>Inert-gas-shielded tungsten-arc or inert-gas-shielded metal-arc</td>
</tr>
<tr>
<td>2. Magnesium or magnesium alloys</td>
<td>Inert-gas-shielded tungsten-arc or inert-gas-shielded metal-arc</td>
</tr>
<tr>
<td>3. High temperature alloys</td>
<td>Inert-gas-shielded tungsten-arc, inert-gas-shielded metal-arc or shielded metal-arc</td>
</tr>
<tr>
<td>4. Nickel and nickel alloys</td>
<td>Inert-gas-shielded tungsten-arc, inert-gas-shielded metal-arc or shielded metal-arc</td>
</tr>
<tr>
<td>5. Cast iron</td>
<td>Inert-gas-shielded tungsten-arc, oxy-acetylene or shielded metal-arc</td>
</tr>
<tr>
<td>6. Die cast alloys, lead and lead alloys</td>
<td>Inert-gas-shielded tungsten-arc, oxy-acetylene or oxy-hydrogen</td>
</tr>
<tr>
<td>7. Dissimilar metals (where one metal or alloy is welded to another – filler metal excepted)</td>
<td>Inert-gas-shielded tungsten-arc, inert-gas-shielded metal-arc, shielded metal-arc or oxy-acetylene</td>
</tr>
<tr>
<td>8. Clad metals and alloys, Low and high-alloy steels</td>
<td>Inert-gas-shielded tungsten-arc, inert-gas-shielded metal-arc, oxy-acetylene or shielded metal-arc</td>
</tr>
</tbody>
</table>

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-12-

DG-300-W
9. Wrought iron

The inert-gas-shielded metal-arc process should be used only if the fabricator has been required to prepare representative test specimens which will duplicate the geometry and position of the joints to be used in the specific fabrication. The welding of any joint in the fabrication should be done only by the welder who prepared the test specimen duplicating the geometry and position of that joint. The purchaser's inspector should satisfy himself that the specimens meet the necessary quality requirements. Proof of ability to use the other welding processes for joining the specific materials should be established by special tests devised for that purpose. A HAPO welding engineer should be consulted in such cases.

Where inert-gas-shielded tungsten-arc process is used, only welding-grade argon of 99.8 percent minimum purity or XX charcoal-purified helium of 99.99 percent minimum purity or mixtures of the two should be used as the shielding atmosphere.

7. PROPORTIONING AND LOCATING WELDS

The proportioning and location of welds are determined by the designer. Information that will be helpful for design calculations appears in the "Welding Handbook", Fourth Edition (published by the American Welding Society, New York) and "Procedure Handbook of Arc Welding Design and Practice" (published by The Lincoln Electric Company, Cleveland, Ohio.) Weld symbols appear on Page 25 of this Guide.

The location of welds is a matter to be decided by the designer after he has determined the physical characteristics of the weld metal to be used and the changes which may occur in the heat-affected zone in the base metal as a result of the welding operation. It is extremely important to realize that when dissimilar metals are to be joined, the factor of dilution has important bearing on the ultimate strength of the weld. A large amount of dilution of the weld metal with the base metal may result in an alloy that will be completely unpredictable as to behavior under service conditions. The designer has no control over this matter beyond alerting the inspector to the condition and including a general statement in the governing specification that unusual dilution of the weld metal with the base metal should be avoided.

8. FABRICATION

8.1 GENERAL

a. Preparation of weld joints for the various metals and alloys listed under 1. "SCOPE should conform to the following listing. Due to the special characteristics and use of most of the materials listed in this Guide, joint designs for these materials should be reviewed by a HAPO welding engineer.
(1) Preparation of joints for the following metals and alloys in the various forms to be welded with the inert-gas-shielded tungsten-arc process should conform to Plate No. 1:

- Cast iron
- Copper and copper alloys
- Die cast alloys
- Dissimilar metals and alloys (where one metal or alloy is welded to another - filler metal excepted)
- High temperature alloys
- Magnesium and magnesium alloys
- Metals and alloys which require inert gas shielding of the heated areas, such as titanium and zirconium
- Nickel and nickel alloys

(2) Preparation of joints for the following metals and alloys in the various forms to be welded with the oxy-acetylene process should conform to Plate No. 2:

- Cast iron
- Copper and copper alloys
- Die cast alloys
- Dissimilar metals and alloys (where one metal or alloy is welded to another - filler metal excepted)
- Wrought iron

(3) Preparation of joints for clad metals and alloys in the various forms to be welded with the shielded metal-arc process should conform to Plate No. 3.

(4) Preparation of joints for lead and lead alloys in the various forms to be welded with the inert-gas-shielded tungsten-arc process, oxy-acetylene process or oxy-hydrogen process should conform to Plate No. 4.

(5) Preparation of joints for the following metals and alloys in the various forms to be welded with the shielded metal-arc process should be done according to the joints shown in the Welding Handbook, American Welding Society, Fourth Edition, Section 1, Chapter 6.

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Cast iron

Copper and copper alloys

Dissimilar metals and alloys (where one metal or alloy is welded to another - filler metal excepted)

High temperature alloys

Low and high-alloy steels

Nickel and nickel alloys

Wrought iron

(6) Joint preparation should be specified on the drawings; or it should be required that joint preparation shall conform to the Welding Handbook, American Welding Society, Fourth Edition, 1957, Section 1, Chapter 4, if the preparation shown there is satisfactory.

b. In those weldments where appearance is a consideration and the inert-gas-shielded tungsten-arc is being used, arc-striking bars should be used to avoid work surface damage adjacent to the weld seams. Arc-striking bars should be copper and should be fastened to the work piece in such a manner that the arc can be started on them and then carried onto the joint to be welded without interruption.

c. "Non-melting" tungsten-alloy electrodes should be used for welding with the inert-gas-shielded tungsten-arc process.

d. Joints to be welded with the inert-gas-shielded tungsten-arc process should have the weld joint root protected on the backside in a manner which will insure against contamination of the weld metal by air, as defined in 9.1, a.,(10) "QUALITY REQUIREMENTS".

e. All joints in pipe and tubing to be welded with the inert-gas-shielded processes should have the weld joint root protected on the backside by an atmosphere of welding-grade argon of 99.8 percent minimum purity or by XX charcoal-purified helium of 99.99 percent minimum purity or by nitrogen of 99.5 percent minimum purity. This is known as the purging atmosphere. No welding should be done until the purge is complete.

f. Metals and alloys which require gas shielding of both sides of the weld and base metal, such as titanium and zirconium, should be protected against detrimental gas contamination and this should be specified on the drawings or related documents. A HAPO welding engineer should be consulted when such materials are to be joined.
g. Welding should not be done when moisture is falling on the surface to be welded. Ordinarily, welding should not be done when the temperature of the base metal is less than 60°F. However, if welding must be done at temperatures below that level, preheating must be used to bring the base metal up to 40°F.

h. A joint which requires rebuilding, prior to welding, should not be repaired without specific permission from the inspector.

8.2 PREPARATION

a. Adequate shielding against drafts and air currents should be provided for all welding operations.

b. Abutting edges and immediate weld area of the sections to be joined should be cleaned mechanically or chemically and thoroughly rinsed to a distance of not less than 1/2 inch from the weld seam edge. If grease, oil or moisture of any description are present on the sections to be welded, such material as may encounter the weld seam through heating should be completely removed. No residual cleaning compounds should be left on surfaces prior to welding. The time interval between cleaning and welding should be such that objectionable oxides will not form prior to welding.

c. The various metals and alloys to be joined by welding should have the abutting edges prepared by machining, grinding, filing, flux-injection cutting process or by inert-gas-shielded tungsten-arc cutting.

Powder cutting* is only applicable to a few metals. Oxy-acetylene cutting can be used on some alloy steels but preheating and post-heating may be necessary to avoid cracking.

When flux-injection cutting** is used, the cut surfaces should be filed or ground back a minimum of 1/32 inch beyond the lowest point of cutting. No grinding on nonferrous metals or alloys should be done with wheels previously contaminated from grinding other materials.

* Powder cutting is the process wherein finely-divided iron powder is injected into the oxygen cutting stream of the oxy-acetylene cutting torch. The iron powder generates additional heat and it is then possible to cut alloy steels and cast irons that could not otherwise be flame cut.

** Flux-injection cutting is defined as cutting by a process which injects a fluxing powder into the oxygen stream for the purpose of assisting the flame-cutting action.
d. If the fabricated unit is to be exposed to corrosive media, care should be taken that no contamination of the work piece results from the use of carbon steel or other tools. Where serious contamination may result from use of the carbon steel tools, stainless steel or beryllium copper tools should be used.

8.3 POSITIONING OF JOINTS TO BE WELDED

a. Joint edges should not be offset from proper alignment by more than one quarter of the thickness of the thinner section at the joint, or 1/5 of the wall thickness in the case of piping or tubing. Offset should never exceed 1/4 inch.

b. Faying surfaces of lap joints or of butt joints of plate and faying surfaces of shapes or castings landing on a backing structure should fit as tightly as practical. Fabricators should be required to obtain approval of fitup from the inspector prior to welding.

c. All parts to be welded should be securely held in alignment by suitable devices or tack welds. Welded joints should be properly supported against sagging until the welded area has cooled.

d. When the first layer of a joint is to be welded without the addition of filler metal, the abutting edges should be in uniform contact throughout the entire length of the joint.

When the first layer of a joint is to be welded with the addition of filler metal, the abutting edges should be either in uniform contact or at uniform spacing throughout the entire length of the joint.

e. All work should be positioned for flat welding when job conditions will permit. Overhead welding should be avoided where possible.

8.4 PREHEATING

a. When preheating is required, its application should be in accordance with accepted practice, subject to the approval of the inspector. Preheating or postheating temperatures should be specified on drawings or related documents governing the specific fabrication.

b. In general, the basic purpose of preheating is to reduce the thermal gradient in the material being welded, thus preventing the formation of undesirable micro-constituents in carbon and alloy steels, cast iron and in some other metals covered by this Guide. Sudden temperature changes set up internal stresses that may result in immediate failure through cracking, or cracking and distortion beyond tolerable limits as a delayed result.
c. It may be necessary to require that the fabricator use methods for determining that the specified preheating temperature is attained and maintained throughout the welding operation in a manner that will be satisfactory to the purchaser's inspector.

d. It may be necessary, in certain instances, to retard the cooling rate of metals or alloys that require preheating and have been welded. The following indicates measures that have proven satisfactory for retarding the cooling rate of metals and alloys that have been welded:

- Slow cooling: Furnace
- Moderate cooling: Lime, mica or sand box
- Faster cooling: Still air (blanketed with asbestos)

e. Preheating prior to welding will,

1. Reduce the danger of formation of cracks in certain metals and alloys,
2. Reduce hardness and strength in certain metals and alloys,
3. Reduce distortion in certain cases,
4. Reduce shrinkage stresses and
5. Materially assist the operator to obtain a more uniform deposit, thus enhancing the quality of the completed weldment.

f. The need for preheating increases as the following factors are changed:

1. The larger the mass being welded.
2. The lower the temperature of the pieces being welded.
3. The lower the atmospheric temperature.
4. The smaller the welding electrode in diameter.
5. The greater the speed of welding.
6. The higher the carbon content of a carbon steel being welded.
7. The higher the manganese content of a carbon steel being welded.
8. The greater the alloy content of any alloy steel being welded.
9. The greater the hardenability of a steel being welded.
(10) The greater the difference in mass between the two pieces being joined.

(11) The more complicated the shape or section of the parts.

g. The proper application of preheating requires an exact knowledge of the composition of the workpiece. Recommendations as to proper preheat and postheat temperatures should be obtained from a HAPO welding engineer.

8.5 WELDING

a. Tack welds, when used, should be kept to a minimum but should be adequate to maintain alignment of the adjacent weld joint edges throughout the welding operation.

b. Tack welds made with the inert-gas-shielded tungsten-arc process should penetrate the joint to the weld root. Such tack welds should be melted out completely in the process of making the weld.

c. All tack welds made with the shielded metal-arc process should have complete penetration to the weld joint root. Fill passes should be fused completely to tack welds, but cracked tack welds should be removed before welding.

d. When sections of different thicknesses are to be joined, the welding heat should be directed so that the abutting edges are uniformly heated, i.e., direct more heat to the heavier section.

e. If the joint to be welded is in the vertical position, the direction of welding should be upward when practical.

f. When the weld requires multilayer welding, the starting and stopping points of successive layers should be staggered. Normally, each layer should be no more than 1/8 inch thick. However, when certain welding processes are used, greater layer thicknesses may be permissible. When multilayer welding with the shielded metal-arc or oxy-acetylene processes, all weld defects and all traces of slag or flux should be removed from preceding weld deposits before welding over them or connecting with them.

g. When the inert-gas-shielded tungsten-arc process is used, the arc should be broken in a manner which will insure gas protection of the weld puddle while it is solidifying.

h. Any gas pockets, cracks or defects which may appear in the progress of welding should be removed prior to the deposit of additional weld metal over that location.
1. If water is used for cooling, all traces of moisture should be removed before continuing welding in that area.

j. Permission should be obtained from the inspector before any straightening or heating operations are performed on welded joints in the following metals and alloys:

- Clad metals and alloys
- Copper and copper alloys
- Die cast alloys
- Dissimilar metals and alloys (where one metal is welded to another - filler metal excepted)
- High temperature alloys
- Low and high-alloy steels
- Magnesium and magnesium alloys
- Nickel and nickel alloys

k. When a weld is being made by the inert-gas-shielded tungsten-arc process, the hot filler rod should not be removed from the inert gas atmosphere.

l. "Wash-pass welding" with the inert-gas-shielded tungsten-arc process should not be permitted as it may reduce the corrosion resistance or strength of the material. The term "wash-pass welding" is defined as the operation of melting only the surface material of the weld deposit with the inert-gas-shielded tungsten-arc, but without the addition of filler material.

m. The minimum number of layers to make a piping or tubing weld should be one layer for each 1/8 inch of wall thickness but not less than two layers per weld joint.

9. QUALITY REQUIREMENTS

9.1 GENERAL

a. Welds should be free of the following surface defects:

(1) Cracks of any description in the weld or base metal.

(2) Crater checks or cracks.
(3) Slag inclusions, oxide inclusions, or gas holes.

(4) Cold lays in the deposited weld metal.

(5) Overlap of weld metal on the base metal.

(6) Undercutting at the edges of welds. None of the finished face of the weld, in the area of fusion of welded joints, should lie below the surface of the base metal adjoining.

(7) Depressions in butt welds below the work piece surface.

(8) Unfilled weld craters.

(9) Tungsten. When particles of tungsten electrode are apparent on the surface of the weld these particles should be removed.

(10) Evidence of damage to the weld metal through air contamination.

(11) Spall of metal which may have been ejected from the shielded metal-arc.

b. Appearance of the weld should be reasonably smooth and uniform. The weld should blend smoothly into the parent metal. Welds having less than 100 percent penetration are unacceptable.

c. The detection of surface flaws by visual examination may be aided substantially in certain instances by dye-penetrant or fluorescent-penetrant inspection. However, only imperfections which are at the surface can be detected by these methods.

9.2 BUTT WELDS

a. Reinforcement of butt-welded joints should be built up uniformly from the surface of the base material to a maximum at the center of the weld.

b. The width of butt welds need be no wider than the top width of the original unwelded joint, but the weld must have complete penetration into the base material at all points of the joint.

c. Butt-welded joints in material over 1/8 inch in thickness, other than piping, should be reinforced at the center of the weld by 20 percent of the thinnest section joined or 1/8 inch, whichever is the least.

d. Butt-welded joints in material 1/8 inch and under in thickness should not be reinforced by more than 50 percent of the thinner section being joined.
c. Weld metal should not protrude **locally** by more than 1/16 inch beyond the inner surface of piping, or tubing, six inches or smaller in diameter. Certain installations may require a more severe limitation.

d. The weld metal should not protrude **locally** by more than 3/32 inch beyond the inner surface of piping or tubing over six inches in diameter.

9.3 FILLET WELDS

a. The faces of all fillet welds should be placed at approximately equal angles to the sections they join. Service conditions may sometimes require that the faces of certain fillet welds be inclined at other specific angles.

b. The throat of fillet welds should not be less than that for the specified weld size. Convex fillet welds should not have a convexity greater than 0.1S plus 0.03 inches, where S is the actual size of the fillet weld in inches.

9.4 SPECIMENS REMOVED FROM WELDED SEAMS FOR SOUNDNESS EXAMINATIONS

a. Welded seams in metals and alloys listed under 1. "SCOPE" are not generally examined by trepanning or removal of specimens from the completed welds. However, when this method of inspection is believed necessary, specimens of each welder's work should be removed at locations chosen by the inspector. Specimens may be removed by trepanning or an equivalent method. Cylindrical specimens or those not having a plane surface should be sectioned across the welds to obtain plane surfaces which shall include the full width of the weld. The plane surface should be polished to a bright, smooth condition. The specimen should then be etched by any method or solution which will reveal the defects without unduly exaggerating or enlarging them.

b. When specimens are defective, the inspector should select the locations for removing two additional specimens for examination. If additional defective specimens are found, then more specimens should be removed at locations chosen by the inspector until the limit of defective welding has been definitely established, or the fabricator may proceed to replace all the welding done by that operator without cutting out additional specimens.

c. Defects are defined as gas pockets, slag inclusions, lack of fusion, and cracks. Defects in specimens other than cracks or lack of fusion should be permissible as follows:
(1) When the width of any inclusion between layers of weld metal substantially parallel with the material surface is not greater than one-half the width of the weld metal where the inclusion is located. (The foregoing does not apply to piping or vessels.)

(2) When the total thickness of all of the inclusions in any plane at approximately right angles to the material surface is not greater than 10 percent of the thickness of the thinner section.

(3) When there are gas pockets that do not exceed 1/32 inch in greatest dimension and where there are no more than six gas pockets of this maximum size per square inch of the weld metal. However, these should be well dispersed.

d. The extent to which sectioning or trepanning of the weld seam is done for the purpose of inspection must be specified.

e. Local radiographic examination may be substituted for the removal of specimens at the option of the fabricator with the approval of the purchaser. The inspector should designate the places to be radiographed. Radiographic techniques and interpretation techniques should be approved by the inspector.

9.5 RADIOGRAPHIC SPOT EXAMINATION

When radiographic spot examination of the weldment is to be required, the following should be imposed: AWS-5766-S, "Standard Specification for Radiographic Spot Examination of Welded Joints".

9.6 RADIOGRAPHIC EXAMINATION

When complete radiographic examination of the weldment is necessary, impose the requirements of the latest edition of Section VIII, "Rules for Construction of Unfired Pressure Vessels, ASME BOILER AND PRESSURE VESSEL CODE". Also, it may be necessary, in certain instances, to state additional requirements above the CODE.

9.7 NONDESTRUCTIVE METHODS OF EXAMINATION

Nondestructive methods of examination other than radiography may be used to detect imperfections within the weld metal. The use of such methods (ultrasonic, etc.) should be contingent upon substantial proof that they are capable of indicating the minimum size of imperfection which the designer wishes to use as a basis for rejection.

10. DEFECTIVE WELDING

Defects should be removed in a manner satisfactory to the inspector and his approval should be obtained prior to repair of any such defects. The repaired areas should be rewelded in a manner conforming to the quality requirements of 9, of this Guide.

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Removal of undercutting by reduction of the base metal section adjacent to the welded seam should not be permitted.

Peening for any purpose should be permitted only in the presence of the inspector.

11. BIBLIOGRAPHY


# American Welding Society Standard Welding Symbols

## Basic Weld Symbols and Their Location Significance

<table>
<thead>
<tr>
<th>Location Significance</th>
<th>Fillet</th>
<th>Plug or Fillet</th>
<th>Arc Steel Symbol</th>
<th>Square</th>
<th>Weld</th>
<th>Surfac</th>
<th>Flange</th>
<th>Resistance Weld Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arrow Side</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Other Side</td>
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## Supplementary Symbols

<table>
<thead>
<tr>
<th>Weld All Around</th>
<th>Field Weld</th>
<th>Contour</th>
<th>Curves</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Typical Welding Symbols

- **Back on Backing Weld Symbol**: Indicates single groove weld.
- **Single-V Groove Welding Symbol Indicating Root Penetration**: Shows the penetration of the weld.
- **Projection Welding Symbol**: Indicates the projection size of the weld.
- **Surfacing Weld Symbol Indicating Built-Up Surface**: Shows the built-up surface of the weld.
- **Double-Fillet Welding Symbol**: Indicates the use of double fillet welds.
- **Welds for Combined Welds**: Shows the combination of weld types.
- **Flash on Upset Welding Symbol**: Indicates the flash on upset weld.
- **Plating Welding Symbol**: Shows the presence of plating welds.
- **Sawing, Force, Thermo, Induction and Flow Welding Symbol**: Shows the use of sawing, force, thermo, induction, and flow welding.
- **Melt-Thru Weld Symbol**: Indicates the melt-thru weld.
- **Single-V Groove Welding Symbol**: Shows the single-V groove weld.
- **Resistance-Spot Welding Symbol**: Shows the resistance-spot weld.
- **Sides and Corner-Flange Weld Symbols**: Shows the sides and corner-flange welds.

## Supplementary Symbols Used with Welding Symbols

- **Weld-All-Around Symbol**: Indicates single or double weld around the joint.
- **Field Weld Symbol**: Shows the field weld.
- **Flash-Contour Symbol**: Indicates flash on contour.
- **Convex-Contour Symbol**: Shows the convex contour.

## Basic Joints: Identification of Arrow Side and Other Side of Joint and Arrow Side and Other Side Member of Joint

- **Arrow Side of Welding Symbol**: Shows the arrow side of the weld.
- **Arrow Side of Fillet Symbol**: Shows the arrow side of the fillet.
- **Corner Joint**: Shows the corner joint.
- **Tee Joint**: Shows the tee joint.
- **Lap Joint**: Shows the lap joint.
- **Edge Joint**: Shows the edge joint.

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## INERT-GAS-SHIELDED TUNGSTEN ARC WELDING

### Welding Current

<table>
<thead>
<tr>
<th>Thickness In.</th>
<th>Type of Weld</th>
<th>Characteristic</th>
<th>Flat</th>
<th>Vertical</th>
<th>Overhead</th>
<th>Amp.</th>
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<td>7 Corner</td>
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<tr>
<td></td>
<td>1/4&quot;</td>
<td>2, 3 Butt</td>
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<td>275-325</td>
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<td></td>
<td>1/2&quot;*Up</td>
<td>2, 3 Butt</td>
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<td>250-300</td>
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### Welding Procedures

**Gas Cup**

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<th>300 Amps DC</th>
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**Argon Flow**

- As Required
PIPING

ACCEPTABLE TYPES OF PREPARATION

SADDLE WELDS

SHEET METAL OR PLATE

SPACING 1/16" TO 3/32"

THICKNESSES UP TO 11 GAUGE - 1/8"

TYPICAL BUTT JOINTS

OXYACETYLENE

PLATE 2
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<th>Single &quot;U&quot;</th>
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<td>45</td>
<td>—</td>
<td>1</td>
</tr>
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<td>5/32</td>
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<td>1</td>
</tr>
<tr>
<td>1/4</td>
<td>45</td>
<td>—</td>
<td>1</td>
</tr>
<tr>
<td>5/16</td>
<td>10</td>
<td>1</td>
<td>1 &amp; 2</td>
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<td>1/2</td>
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<td>1</td>
</tr>
<tr>
<td>2</td>
<td>—</td>
<td>10</td>
<td>1</td>
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</table>

Steel side, flat position.

CLAD METALS AND ALLOYS

METAL-ARC

PLATE 3
LAP JOINT
MAKE OVERLAP ABOUT 5 TIMES THICKNESS.

FLANGED JOINT
USE FOR SHEET UP TO 1/16" THICK

BEVELED BUTT JOINT
USE FOR SHEET OVER 1/4" THICK

FLANGE WELD
FOR 1 1/2" INSIDE DIAMETER EXTRA STRONG LEAD PIPE.

FOR PIPE WITH 1/8" WALL THICKNESS; OR LESS.

FOR PIPE OVER 1/8" WALL THICKNESS.

WELDED CUP JOINT
FOR 1 1/2" INSIDE DIAMETER EXTRA STRONG LEAD PIPE.

LEAD AND LEAD ALLOYS
INERT-GAS-SHIELDED TUNGSTEN-ARC, OXY-ACETYLENE AND OXY-HYDROGEN

PLATE 4

DG-300-W
The processes for joining different metals will indicate that high carbon steels cannot be joined directly without a joining method. The symbol (*) indicates the intersection of aluminum and stainless steels. Note: The square marked this process for joining dissimilar metals and alloys.
DG-301-W

GUIDE FOR

WELDED JOINTS
1. **SCOPE**

This Guide is to assist in the preparation of drawings and specifications for welded fabrication.

2. **GENERAL**

Special characteristics of certain metals and alloys dictate the specific joint to be used at a given location in a fabricated item. Such information must be obtained from literature relating to the material being considered.

3. **LOCATION OF WELDS**

The location of welds is a matter to be decided by the designer after he has determined the physical characteristics of the weld metal to be used and the changes which may occur in the heat-affected zone in the base metal as a result of the welding operation. It is extremely important to realize that when dissimilar metals are to be joined, the factor of dilution has important bearing on the ultimate strength of the weld. A large amount of dilution of the weld metal with the base metal may result in an alloy that will be completely unpredictable as to behavior under service conditions. The designer has no control over this matter beyond alerting the inspector to the condition and including a general statement in the governing specification that unusual dilution of the weld metal with the base metal should be avoided.

4. **PROPORTIONING OF WELDS**

The proportioning of welds is decided by the designer. Information that will be helpful for design calculations appear in the "Welding Handbook," Fourth Edition (published by the American Welding Society, New York) and "Procedure Handbook of Arc Welding Design and Practice" (published by the Lincoln Electric Company, Cleveland, Ohio).
BUTT JOINTS

1. PLAIN BUTT JOINT RECOMMENDED FOR PLATES LESS THAN 3/8" THICK. JOINT IS INEXPENSIVE TO PREPARE, SUITABLE FOR ORDINARY LOADS IF FULL PENETRATION IS SECURED.

2. SINGLE V BUTT JOINT USED FOR 3/8" PLATE OR THICKER. JOINT PREPARATION COSTS MORE THAN (1) AND MORE ELECTRODE IS USED, SUITABLE FOR ORDINARY LOADS.

3. DOUBLE V BUTT JOINT IN GENERAL IS A STRONGER JOINT THAN (2) AND JOINT PREPARATION COST IS GREATER BUT LESS ELECTRODE IS USED, SUITABLE FOR ORDINARY LOADS WHERE USED WITH 1/2 PLATE OR THICKER.

4. SINGLE U BUTT JOINT USUALLY USED FOR JOINTS THICKER THAN (3). JOINT PREPARATION COST IS GREATER BUT LESS ELECTRODE IS USED, WELD IS ON ONE SIDE EXCEPT SINGLE BEAD WHICH IS PUT ON LAST, MEETS ALL USUAL LOAD CONDITIONS AND IS ASSOCIATED WITH BEST QUALITY WORK.

5. DOUBLE U BUTT JOINT USED WHERE WELDS CAN BE MADE FROM BOTH SIDES. FOR USE ON PLATES THICKER THAN (4), JOINT PREPARATION COSTS MORE THAN DOUBLE V BUT LESS ELECTRODE IS REQUIRED, SATISFACTORY FOR ALL TYPES OF LOADS.

TEE JOINTS

6. PLAIN FILLET WELDED TEE JOINT JOINT PREPARATION IS NOT NECESSARY, CAN BE USED ON ALL ORDINARY PLATE SIZES. EFFECTIVENESS IS GREATER FOR WELDS IN LONGITUDINAL SHEAR. USE WITH CAUTION FOR WELDS HEAVILY LOADED TRANSVERSELY.

7. SINGLE V TEE JOINT FOR WORK WELDED FROM ONE SIDE ON PLATES 1/2" THICK OR LESS. COSTS MORE FOR JOINT PREPARATION THAN (6) BUT LESS ELECTRODE IS REQUIRED. STRONGER THAN (6) FOR ALL SEVERE LOADS.

8. DOUBLE V TEE JOINT USED ON PLATES OVER 1/2" THICK AND REQUIRES LESS ELECTRODE THAN (6). WELD FROM BOTH SIDES CAN BE USED FOR SEVERE LONGITUDINAL OR TRANSVERSE LOADS.

9. SINGLE U TEE PLATE USED FOR PLATES 1" THICK OR MORE. WELDED FROM ONE SIDE EXCEPT FOR SINGLE BEAD WHICH IS PUT ON LAST. COSTS MORE FOR JOINT PREPARATION THAN (7) BUT LESS ELECTRODE IS USED. FOR SAME CLASS OF LOADS AS SINGLE V.

10. DOUBLE U TEE JOINT FOR PLATES 1" THICK OR MORE WHICH CAN BE WELDED FROM BOTH SIDES. JOINT PREPARATION COSTS MORE THAN (8) BUT LESS ELECTRODE IS REQUIRED. CAN BE USED FOR VERY SEVERE LOAD CONDITIONS, ALL CLASSES.

CORNER JOINTS

11. FLUSH CORNER JOINT USED ON 12 GAUGE PLATE OR LIGHTER. MAY BE USED WITH CAUTION ON HEAVIER PLATE WHERE LOADING ARE NOT SEVERE.

12. HALF OPEN CORNER JOINT. FOR USE ON ALL PLATE THICKNESSES WHERE WELDING CAN BE DONE FROM BOTH SIDES. FOR MAXIMUM STRENGTH UNDER SEVERE LOAD CONDITIONS.

13. FULL OPEN CORNER JOINT. FOR USE ON 1/2 GAUGE OR HEAVIER WHERE WELDING CAN BE DONE FROM BOTH SIDES. FOR MAXIMUM STRENGTH UNDER SEVERE LOAD CONDITIONS.

LAP JOINTS

14. SINGLE BEAD LAP JOINT. MAY BE USED FOR ALL SIZES OF PLATE WHERE JOINTS ARE NOT SUBJECT TO SEVERE FATIGUE OR IMPACT LOADS.

15. DOUBLE BEAD LAP JOINT, STRONGER THAN (14) AND MAY BE USED FOR HEAVIER LOAD CONDITIONS. BEADS SHOULD BE FULL SIZE. THE BUTT JOINTS SHOWN ARE MORE EXPENSIVE TO PREPARE BUT ARE PREFERRED WHERE SERVICE IS VERY SEVERE.

EDGE JOINT

16. EDGE JOINT MAY BE USED ON 1/4" PLATE OR LIGHTER WHERE LOADING ARE NOT SEVERE.

GENERAL NOTES:

1. THE RELATION OF TYPE OF WELD TO THE THICKNESS OF PLATES REQUIRES JUDGEMENT WHERE THE TERM "THICKER" IS USED. USUALLY THE THICKNESS SHOULD BE INTERPRETED AS MEANING ONE STANDARD SIZE LARGER THAN THE SIZE SPECIFIED. IF THE LOAD IS LIGHT, THEN TWO SIZES LARGER, ETC.

2. THE COST OF A WELDED JOINT DEPENDS ON THE EXTENT OF JOINT PREPARATION AND THE AMOUNT OF ELECTRODE USED. IN OTHER WORDS IT IS POSSIBLE TO OBTAIN AN ECONOMICAL WELD WHERE PREPARATION COSTS ARE HIGHER THAN FOR THE REFERENCE WELD, BUT ELECTRODE COSTS ARE LOWER AND VICE VERSA.
# Weld Joint Nomenclature

## Edge Joints
- **1** Flanged
- **2** Butt Joint
- **3** Closed Single-Flanged
- **4** Open Single-Flanged
- **5** Closed Double-Flanged
- **6** Open Double-Flanged
- **7** Closed Upset
- **8** Open Upset
- **9** Closed Square
- **10** Open Square
- **11** Closed Single-V
- **12** Open Single-V
- **13** Closed Double-V
- **14** Open Double-V
- **15** Closed Single-Bevel
- **16** Open Single-Bevel
- **17** Closed Double-Bevel
- **18** Open Double-Bevel
- **19** Closed Single-U
- **20** Open Single-U
- **21** Closed Double-U
- **22** Open Double-U
- **23** Strapped Closed Square
- **24** Strapped Open Square
- **25** Strapped Closed Single-V
- **26** Strapped Open Single-V
- **27** Strapped Closed Single-U
- **28** Strapped Open Single-U

## Lap Joints
- **28** Single
- **29** Double
- **30** Single-Strap
- **31** Double-Strap
- **32** Closed Joggled Single
- **33** Open Joggled Single
- **34** Flanged Single
- **35** Flanged Closed Joggled Single
- **36** Flanged Open Joggled Single
- **37** Linear Slotted
- **38** Circular Slotted

## Corner Joints
- **39** Closed Lapped
- **40** Open Lapped
- **41** Closed
- **42** Open

## Tee Joints
- **43** Closed Square
- **44** Open Square
- **45** Closed Single-Bevel
- **46** Open Single-Bevel
- **47** Closed Double-Bevel
- **48** Open Double-Bevel
- **49** Closed Single-J
- **50** Open Single-J
- **51** Closed Double-J
- **52** Open Double-J
# Selection of Grooves for Weld Joints

## Selection of Groove for Butt Joint

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<tr>
<th>Plate Thickness (In.)</th>
<th>Type of Groove</th>
<th>Plate</th>
<th>Weld Depth</th>
<th>One Side</th>
<th>Both Sides (See Note)</th>
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<tbody>
<tr>
<td>1/8 to 1/4 inl</td>
<td>Square</td>
<td>Plate Thickness</td>
<td>5/32</td>
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<tr>
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<td>Square</td>
<td>Plate Thickness</td>
<td>5/32</td>
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<tr>
<td>1/4 to 1 1/4'</td>
<td>V</td>
<td>Plate Thickness</td>
<td>less than</td>
<td>*</td>
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<tr>
<td>1 1/4 to 2 1/2</td>
<td>V, U, or Mod. U</td>
<td>Plate Thickness</td>
<td>less than</td>
<td>*</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>but 1 1/4&quot; or greater</td>
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</tr>
<tr>
<td>2 1/8 to 3/8&quot; up</td>
<td>U, Mod. U or V</td>
<td>Plate Thickness</td>
<td>See Above (U or Mod. U)</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>but 2 1/8&quot; or greater</td>
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<td></td>
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<td></td>
<td>less than 2 1/8&quot; (V for depth less than 1 1/4&quot;)</td>
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With or without permanent backing strip.

Notes: "Both sides" preferred to "One side", accessibility and shop facilities permitting.

## Selection of Groove for L-Joint

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<th>Type of Groove</th>
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<th>Joint Cross-Section</th>
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<td>A B</td>
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<td>All</td>
<td>Fillet at &quot;B&quot;</td>
<td>A B</td>
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<tr>
<td>1/4 to 1 1/4'</td>
<td>Square Groove at &quot;A&quot;</td>
<td>Partial Penetration</td>
<td>A B</td>
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<tr>
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<td>Partial Penetration</td>
<td>A B</td>
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<td>V</td>
<td>Plate Thickness</td>
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<td>V</td>
<td>U or Mod. U Groove</td>
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<td>V</td>
<td>V Groove</td>
<td>less than 1 1/4&quot;</td>
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With or without a fillet weld at "B".

Notes: A small weld at "A" and "B" is better than a large weld at "A" or "B". Where possible, extend one member to form a T-joint and use fillet welds.

## Selection of Groove for T, Lap, and Edge Joints

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<th>Plate Thickness (In.)</th>
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<td>B A</td>
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<td>J Groove</td>
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</tr>
<tr>
<td>1/8&quot; to 1&quot;</td>
<td>J Groove</td>
<td>Plate Thickness</td>
<td>less than 3/8&quot; or greater</td>
<td>B A</td>
<td></td>
</tr>
<tr>
<td>1&quot; Up</td>
<td>All</td>
<td>J Groove</td>
<td>Plate Thickness</td>
<td>B A</td>
<td></td>
</tr>
<tr>
<td>Lap</td>
<td>All</td>
<td>Fillet</td>
<td>--</td>
<td>B A</td>
<td></td>
</tr>
<tr>
<td>Edge</td>
<td>1/16&quot; to 3/8&quot;</td>
<td>Square Groove</td>
<td>Partial Penetration</td>
<td>--</td>
<td></td>
</tr>
</tbody>
</table>

With or without a fillet weld on either or both sides of the above T-joints.

Notes: A small weld on both sides is better than a large weld on either side.
WELD JOINT COMPARISON

FIG. | APPLICATION
--- | ---
1 | POOR JOINT FOR SHEET METAL BECAUSE OF PROBABLE OXIDATION IN JOINT.
2 | STRONGER JOINT THAN FIG. 1 THOUGH PREPARATION COSTS MORE.
3 & 4 | LESS DIFFICULT TO WELD THAN FIG. 5 OR 9.
5 | SEE ITEMS 3 & 4.
6, 7 | PREPARATION OF PARTS NOT REQUIRED. FIGURE 7 IS DIFFICULT TO HOLD IN ALIGNMENT.
8, 8 | SEE ITEMS 3 & 4.
9 | PREPARATION OF PARTS NOT REQUIRED.
10 & 12 | SIMPLE DESIGNS FOR PLATE BUTT WELD.
13 | CAN BE USED FOR PLATE MATERIAL BUT NOT FOR SHEET METAL.
14 | PREFERABLE TO FIG. 8 FOR THICK PLATES.
15 | ALTERNATE METHOD TO FIG. 14 FOR THICK PLATES.
16 | GIVES UNSATISFACTORY WELD PENETRATION.
17 | ALTERNATE METHOD TO FIGS. 14 OR 15 FOR THICK PLATES.
18 | STRONGER WELD THAN FIG. 14, 15, 16, OR 17.
19 & 20 | USABLE METHOD THOUGH NOT GOOD PRACTICE.
21 | SATISFACTORY THREE PIECE WELD.
22, 23 | GOOD JOINTS IF CAREFULLY DONE. NOTE THE AMOUNT OF FILLER MATERIAL REQUIRED.
24 & 25 | GIVES COMPLETE WELD PENETRATION. REQUIRES SKILLED WELDER.
26 & 27 | WILL NOT RESULT IN SOLID JOINT.
28 | SHOWS BEVELING REQUIRED FOR BUTT WELDING PIPE SECTIONS.
29 | GOOD JOINTS FOR LONGITUDINAL PIPE SEAMS.
30 | GOOD JOINTS FOR CYLINDRICAL TANK BOTTOMS.
31, 32, 33 | GOOD JOINTS FOR PIPE SECTIONS AT RIGHT ANGLES.
34 & 35 | JOINTS FOR PIPE SECTION ELBOWS.
36 | SPECIAL FLANGE FOR PIPE CONNECTIONS.
37 & 38 | JOINTS USED FOR FABRICATING FLANGE ON END OF PIPE.
39 | JOINT FOR WELDING SMALL ROD.
40 | JOINT FOR WELDING LARGE ROD.
41 | THE POINT AT ENDS OF ROD IS NOT ACCEPTABLE.
42 | JOINT FOR TANK BOTTOM NOT REQUIRING STRENGTH.
43 | GOOD JOINT FOR GAS CONTAINER BOTTOM.
44 | STRONG JOINT FOR PARTITION WELD.
45 & 46 | UNDESIRABLE FOR CYLINDER BOTTOMS.
47 | ACCEPTABLE JOINT FOR CYLINDER BOTTOMS.
48, 49 & 50 | NOT SUITABLE FOR HIGH PRESSURE.
51 | PIPE BUTT WELD WHERE SECTION THICKNESS IS UNIFORM.
52 | PIPE BUTT WELD FOR UNEVEN SECTION THICKNESS. TO BE AVOIDED.
53 | GOOD PIPE BUTT WELD FOR UNEVEN SECTION THICKNESS. REQUIRES LESS FILLER MATERIAL THAN FIG. 52.

PLATE D
### TYPICAL WELD JOINT DETAILS

<table>
<thead>
<tr>
<th>Joint Type</th>
<th>Welding Position</th>
<th>Effective Throat Thickness</th>
<th>Max. T</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPEN SQUARE-BUTT JOINT</td>
<td>T-unlimited</td>
<td>6T</td>
<td>T &gt;= $T$</td>
</tr>
<tr>
<td>SINGLE-U BUTT JOINT</td>
<td>T-unlimited</td>
<td>6T</td>
<td>T &gt;= $T$</td>
</tr>
<tr>
<td>SQUARE-BUTT JOINT</td>
<td>T-unlimited</td>
<td>6T</td>
<td>T &gt;= $T$</td>
</tr>
<tr>
<td>DOUBLE-U BUTT JOINT</td>
<td>T-unlimited</td>
<td>6T</td>
<td>T &gt;= $T$</td>
</tr>
<tr>
<td>SINGLE-V BUTT JOINT, WELDED ONE SIDE</td>
<td>T-unlimited</td>
<td>6T</td>
<td>T &gt;= $T$</td>
</tr>
<tr>
<td>DOUBLE-V BUTT JOINT</td>
<td>T-unlimited</td>
<td>6T</td>
<td>T &gt;= $T$</td>
</tr>
<tr>
<td>DOUBLE FILLET WELDED LAP JOINT</td>
<td>T-unlimited</td>
<td>6T</td>
<td>T &gt;= $T$</td>
</tr>
</tbody>
</table>

**Notes:**
- Root need not be chipped before welding second side.
- Effective Throat Thickness = T
- Max. T = $T$
ALLOWABLE LOADS ON FILLET WELDS

\[ P = 9.6 \text{DL} \]

(Based on 13,600 psi, shear
on throat = 9.6 ksi on leg)

<table>
<thead>
<tr>
<th>L</th>
<th>( \frac{1}{16} )</th>
<th>( \frac{1}{8} )</th>
<th>( \frac{1}{4} )</th>
<th>( \frac{3}{16} )</th>
<th>( \frac{1}{8} )</th>
<th>( \frac{3}{16} )</th>
<th>( \frac{1}{8} )</th>
<th>( \frac{3}{16} )</th>
<th>( \frac{1}{8} )</th>
<th>( \frac{3}{16} )</th>
<th>( \frac{1}{8} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.8</td>
<td>1.4</td>
<td>1.6</td>
<td>1.8</td>
<td>2.1</td>
<td>2.7</td>
<td>2.8</td>
<td>3.0</td>
<td>3.3</td>
<td>3.6</td>
<td>3.8</td>
</tr>
<tr>
<td>2</td>
<td>1.6</td>
<td>3.1</td>
<td>3.4</td>
<td>3.7</td>
<td>4.2</td>
<td>4.9</td>
<td>5.0</td>
<td>5.3</td>
<td>5.6</td>
<td>5.9</td>
<td>6.1</td>
</tr>
<tr>
<td>3</td>
<td>2.4</td>
<td>4.4</td>
<td>4.8</td>
<td>5.2</td>
<td>6.1</td>
<td>7.0</td>
<td>7.2</td>
<td>7.5</td>
<td>8.0</td>
<td>8.4</td>
<td>8.6</td>
</tr>
<tr>
<td>4</td>
<td>3.2</td>
<td>5.6</td>
<td>6.2</td>
<td>6.8</td>
<td>8.1</td>
<td>9.4</td>
<td>9.8</td>
<td>10.3</td>
<td>11.0</td>
<td>11.6</td>
<td>11.8</td>
</tr>
<tr>
<td>5</td>
<td>4.0</td>
<td>7.2</td>
<td>8.0</td>
<td>8.8</td>
<td>10.5</td>
<td>12.0</td>
<td>12.4</td>
<td>13.0</td>
<td>14.0</td>
<td>14.8</td>
<td>15.1</td>
</tr>
</tbody>
</table>

The allowable loads shown are based on the shear value of 13,600 psi and apply only to mild carbon steel. The allowable loads for other metals or alloys will vary directly with their shear values.

The above table is based on AISC and the uniform building code and is satisfactory for structural fabrication. The more conservative AWS-AWSA values are required for tank construction where the allowable shear value is 15,000 psi and the efficiency is limited to 65% for fillet welds under transverse shear (P=6.9 kips) and 50% efficiency for fillet welds under longitudinal shear (P=5.3 kips).

Allowable loads for fillet welds in AWS-AWSA tank construction may be found by using the following values for the specific weld size:

Transverse Shear - 0.72 times table value

Longitudinal Shear - 0.53 times table value
### Weld Joint Strength Formulas

<table>
<thead>
<tr>
<th>Description</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal stress, psi</td>
<td>$S = \frac{P}{h_1}$</td>
</tr>
<tr>
<td>Unit stress, psi</td>
<td>$S = \frac{P}{(h_1 + h_2)}$</td>
</tr>
<tr>
<td>Bending moment, in lb</td>
<td>$M = \frac{P}{(h_1 + h_2)}$</td>
</tr>
<tr>
<td>External load, lb</td>
<td>$D = \frac{P}{(h_1 + h_2)}$</td>
</tr>
<tr>
<td>Moment of inertia, inch units</td>
<td>$I = \frac{P}{(h_1 + h_2)}$</td>
</tr>
<tr>
<td>Linear distance</td>
<td>$L = \frac{P}{(h_1 + h_2)}$</td>
</tr>
<tr>
<td>Size of weld</td>
<td>$H = \frac{P}{(h_1 + h_2)}$</td>
</tr>
</tbody>
</table>

**Plate G**

**DG-301-W**
# American Welding Society Standard Welding Symbols

## Basic Weld Symbols and Their Location Significance

<table>
<thead>
<tr>
<th>Location Significance</th>
<th>Fillet</th>
<th>Filler or Eloy</th>
<th>Arc-Beam</th>
<th>Square</th>
<th>Bevel</th>
<th>J</th>
<th>Flare</th>
<th>Flare Bevel</th>
<th>Back or Facing</th>
<th>Weld-Thru</th>
<th>Surfacing</th>
<th>Root</th>
<th>Coron</th>
<th>Resistance Weld Symbol</th>
<th>Projection Resistance Flash or Upset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arrow Side</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Side</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Both Sides</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Arrow Side</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Supplementary Symbols

### Typical Welding Symbols

- **Back or Facing Weld Symbol**: Indicates the焊缝的背面或侧面。
- **Root Groove Welding Symbol**: Indicates root penetration。
- **Surface Welding Symbol**: Indicates built-up surface。
- **Double-Bevel Groove Welding Symbol**: Indicates a total depth of welding.
- **Welding Symbols for Combined Welds**: Includes symbols for both bevel and fillet welds.
- **Plug Welding Symbol**: Indicates an electrically melted spot weld.
- **Threading and Flow Welding Symbol**: Shows methods of threading and flow welding.
- **Weld Pressure Welding Symbol**: Indicates pressure welding.
- **Flash or Upset Welding Symbol**: Shows methods of flashing or upsetting.
- **Butt Joint**: Indicates a joint where the plates are butt-welded together.
- **Corner Joint**: Indicates a joint where the plates are corner-welded together.
- **Edge Joint**: Indicates a joint where the plates are edge-welded together.

## Supplementary Symbols Used with Welding Symbols

- **Weld-All-Around Symbol**: Indicates that the weld is circumferentially around the joint.
- **Field Weld Symbol**: Indicates a weld made in the field.
- **Flash-Contour Symbol**: Indicates a weld made using flash contouring.
- **Convex-Contour Symbol**: Indicates a weld made using convex contouring.

## Basic Joints

- **Butt Joint**: Joint where two plates are butted together.
- **Corner Joint**: Joint where two plates meet at a corner.
- **Edge Joint**: Joint where two plates are edge-welded together.
- **Tee Joint**: Joint where a plate is welded to the side of another plate.
- **Lap Joint**: Joint where two plates are overlapped and welded.
GENERAL ELECTRIC
HANFORD ATOMIC PRODUCTS OPERATION

CAPE-1072-

DG-400-I

DESIGN GUIDE

FOR

FLOW RESTRICTING ORIFICES

AUGUST 1, 1956
I. PURPOSE

The Flow Restricting Orifice Design Guide is prepared to serve as a guide to design engineers and maintenance personnel in sizing flow restricting orifices. The guide is not suitable for or intended as a substitute for construction specifications.

II. GENERAL

Flow restricting orifices may be used as flow throttlers under certain conditions or flow limiting devices under other conditions. Since liquids and gases have different characteristics they will be treated separately in this design guide. The usage of flow restricting orifices is limited. They cannot be used in lieu of valves in most cases. In this guide the orifice will be considered to be "throttling" when flow velocities are below critical and "limiting" when flow velocities are critical. Below are some services where flow restricting orifices may be successfully used:

a. To throttle cooling water flow to a condenser when upstream and downstream pressures are constant and cooling load is constant or control is not critical.

b. To throttle gas flow in a closed dryer-regenerating system.

c. To limit the flow in a gas line when the gas is being measured by a positive displacement meter which could be damaged by high flows.

Unless otherwise stated, all references to orifices will be the sharp-edged, concentric type.

Caution: The pressure downstream from an orifice will rise to full line pressure in the event of a downstream stoppage. Therefore, piping must be adequate for full line pressures or relief valves provided.

III. GAS OR VAPOR FLOW RESTRICTING ORIFICES

The maximum gas or vapor flow through a line can be "limited" by a sharp-edged concentric orifice when the pressure drop across it (measured at 2½ diameters upstream and 8 diameters downstream) is more than one-half of the upstream absolute pressure. At a downstream pressure of approximately 50 per cent of upstream absolute pressure the velocity reaches that of sound and a further decrease in the downstream pressure to zero will only increase the flow about 12 per cent.
a. To "limit" the gas or vapor flow to a selected maximum, size the orifice to give a critical pressure drop ($\frac{1}{2}$ of the absolute upstream pressure) at the given flow. The orifice may be sized by formula (See Foxboro Flow Meter Engineering, page 252, for example) or by using one of the flow slide rules. The Foxboro combination valve sizing and meter calculation rule is adequate for this. In any case calculate the pressure drop at the pipe taps ($2\frac{1}{2}$ pipe diameters upstream and 8 diameters downstream). Note that the pressure drop factor used is in terms of inches of water.

Example:

Fluid: CO$_2$, Sp. Gr. 1.5 (Use Sp. Gr. at operating temperature)
Max. Allowable Flow: 1,000 CFM
(60,000 CFH)
Upstream Pressure: 115 psia
Downstream Pressure: 57 psia or less
Pressure Drop: 1,580 inches water (57 pounds $\times$ 27.7 inches per pound)
Pipe Size: 2.067" I. D.
From Foxboro Valve Rule: $d/D^*$ pipe taps $= 0.48$
\[ d = 0.48 \times 2.067 = 1.00 \text{ inches} \]

b. To "throttle" the gas or vapor flow to a certain rate, size the orifice to give the available pressure drop at the desired rate of flow. Permanent pressure drop is required so you will use the drop $2\frac{1}{2}$ pipe diameters upstream and 8 diameters downstream (pipe taps). Both the upstream and downstream pressures must be constant or the flow rate will vary, in proportion to the square root of the head change (when below critical velocity).

Example:

Fluid: CO$_2$, Sp. Gr. 1.5 (Use Sp. Gr. at operating temperature)
Desired Flow: 500 CFM (30,000 CFH)
Upstream Pressure: 115 psia
Downstream Pressure: 90 psia
Pressure Drop: 693 inches water (25 pounds $\times$ 27.7 inches per pound)
Pipe Size: 2.067" I. D.
From Foxboro Valve Rule: $d/D^* = 0.39$
\[ d = 0.39 \times 2.067 = 0.81 \text{ inches} \]

* Where $d =$ orifice diameter
$D =$ inside pipe diameter
IV. LIQUID FLOW RESTRICTING ORIFICES

A. Flow throttling orifices for liquids may be calculated directly from a flow meter slide rule by calculating the $d/D$ required for the pressure drop, using $2\frac{1}{2}$ and $8$ diameter pipe taps. The combination valve and meter sizing rules are adequate for this service. The calculation may also be made by formula. If the pressure conditions change from the calculated values, the flow will vary approximately in proportion to the square root of the differential pressure across the orifice. The pressure drop factor used in the calculation is in terms of inches of water.

Example:

Fluid: Water (Use Sp.Gr. at operating temperature)  
Desired Flow: 4 gpm  
Upstream Pressure: 100 psig  
Downstream Pressure: 75 psig  
Pressure Drop: 693 inches water (25 pounds x 27.7 inches per pound)  
Pipe Size: 1.049" I. D.  
From Foxboro Valve Rule: $d/D = 0.21$  
$$d = 0.21 \times 1.049 = 0.220 \text{ inches}$$

Note a: The above problem might arise if it were required to inject 4 gpm of water from a 100 psig header into a 75 psig line.

Note b: Unlike a flow measuring orifice, a pressure drop may not be "assumed" for flow throttling orifice. Both upstream and downstream pressures must be known.

B. Flow limiting orifices for liquids are not discussed here because liquid flow velocities do not reach the critical velocity.

REFERENCES: Flow Meter Engineering, L. K. Spink  
ISA Journal, January, 1955, page 28  
Foxboro Valve and Meter Sliderule, Form 2183
DG-401-I

GUIDE

for

INSTRUMENT TUBING AND FITTINGS
Purpose

This guide is intended for use by design engineers, plant maintenance engineers, foremen and others who specify or use instrument tubing and fittings. It is the intent of this guide to provide the user with a list of fittings and tubing suitable for the service-pressure-temperature conditions listed.

Use

Each tubing or fitting is specified by reference to the appropriate American Standards Association (ASA), American Society for Testing Materials (ASTM), or Society of Automotive Engineers (SAE) specification except in a few instances where materials are specified by a manufacturer or equal.

Some effort has been made to list the fittings in numerical order of preference; however, it is recognized that certain applications may require a particular type of fitting because of space limitations, maintenance conditions, or other reasons. Therefore, any listed fitting may be selected for the service-pressure-temperature conditions given when the preferred type does not meet all requirements.
Service: Water, Air, Argon, CO₂, Nitrogen, Helium
Pressure: 100 psi maximum
Temperature: 100 F maximum

Fittings:* Compression type with tube support sleeve. Imperial Poly-Flo Fittings or Equivalent.

Material:
Fittings: Forged Brass or stress-relieved brass bar stock

Tubing:* Composition: Virgin Polyethylene resin
Tolerances: Wall and OD + 0.005"
Molecular Weight: 25000 minimum
Specific Gravity: 0.93 minimum
Tensile Strength: 2300 psi at 70 F
Yield Strength: 1600 psi at 70 F
Softening Point: 209 F
Sheath: Extruded Virgin Polyvinyl Chloride .0625" minimum wall thickness
Tubing Minimum Wall Thickness: 1/4" OD x .040" wall; 3/8" OD x .062" wall

Dekoron Poly-Cor "P" Tubing or equivalent
Plastic tubing should be supported more frequently than copper to prevent low points and unsightly sagging. In some instances, copper tubing will be more suitable for this reason; see page 3.

Test:
For Control Systems, pressure test at maximum pilot pressure (usually 15 psi) with oil-free air or nitrogen in accordance with Instrument Society of America RP-7.1, "Recommended Practice for Pneumatic Control Circuit Pressure Test"

For other systems, hydrostatic test at 1.5 times working pressure. Use pressure drop method for leak detection. (Dry with oil-free air or nitrogen if moisture is a problem) See Appendix for apparatus for a pneumatic pressure drop test for tubing.

Cleaning: Blow out with oil-free air or nitrogen.

*All fittings and tubing listed on Page 3 of this guide are also suitable for this service.

Revised 7-21-61
Service: Water, Oil, Air, Argon, CO₂, Helium, Nitrogen, Condensate
Pressure: 100 to 200 psi
Temperature: 100 F maximum

Fittings:* 1. Grip or bite Flareless Type ASA B31.1
2. 45° Flared Type ASA B70.1
3. Compression Type ASA B31.1
4. Silver Brazed Socket Type ASA B31.1
5. Inverted Flare Type ASA B31.1
6. Solder Type ASA B16.22

Limitation: Do not use solder type where mechanical vibration, hydraulic shock, or possible thermal shock are present. (Example: Steam Condensate)

7. Compression type flexible fittings may be used for applications where severe vibration is a factor. (Max. tube size 1/2" OD.)
   Imperial Flex Fitting or equivalent.

Fittings Material: Forged brass or stress-relieved brass bar stock SAE 88 and SAE 72 except wrought copper or wrought bronze for solder fittings.

Tubing:* 1. Non-corrosive atmosphere: bare or bundled seamless copper tubing, per ASTM B75, soft annealed temper, except where rigidity is required, light drawn temper should be used.
2. Corrosive Atmosphere: Copper Tubing, ASTM B75 with 1/32" minimum thickness polyethylene or vinyl plastic extruded over each tube; or bundled bare tubes with 1/16" minimum polyethylene or vinyl plastic sheath extruded over all. Dekoron Coated Instrument Tubing or Dekoron Metl-Cor or equivalent.

Tubing Minimum Wall Thickness for 200 psi Working Pressure

<table>
<thead>
<tr>
<th>Tubing Size</th>
<th>Wall Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/8&quot; OD</td>
<td>.030&quot; Wall</td>
</tr>
<tr>
<td>3/16&quot; OD</td>
<td>.030&quot; Wall</td>
</tr>
<tr>
<td>1/4&quot; OD</td>
<td>.030&quot; Wall</td>
</tr>
<tr>
<td>5/16&quot; OD</td>
<td>.032&quot; Wall</td>
</tr>
<tr>
<td>3/8&quot; OD</td>
<td>.032&quot; Wall</td>
</tr>
<tr>
<td>1/2&quot; OD</td>
<td>.035&quot; Wall</td>
</tr>
<tr>
<td>5/8&quot; OD</td>
<td>.049&quot; Wall</td>
</tr>
<tr>
<td>3/4&quot; OD</td>
<td>.049&quot; Wall</td>
</tr>
</tbody>
</table>

Test: Hydrostatic test at 1.5 times working pressure. Use pressure drop method for leak detection. (Dry with oil-free air or nitrogen if moisture is a problem.) See Appendix for a pneumatic pressure drop test for tubing.

Cleaning: Flush with line fluid or blow out with oil-free air or nitrogen.

*These fittings and tubing are also suitable for the service listed on Page 2 of this guide.

Revised 7-21-61
Service: Water, Oil, Air, Argon, CO₂, Helium, Nitrogen, Condensate
Pressure: 200 to 500 psi
Temperature: 100 F maximum

Fittings:
1. Grip or Bite Flareless Type ASA B31.1
2. 45° Flared Type ASA B70.1
3. Silver Brazed Socket Type ASA B31.1
4. Compression Type (Max. Size 1/2" Tube) ASA B31.1
5. Inverted Flare Type ASA B31.1

Fittings Material: Forged brass or stress-relieved brass bar stock in accordance with SAE 88 and SAE 72.

Tubing:
1. Non-Corrosive Atmosphere: Bare or bundled seamless copper tubing, per ASTM B75, soft annealed temper, except where rigidity is required, light drawn temper should be used.
2. Corrosive atmosphere: Copper tubing, ASTM B75 with 1/32" minimum thickness polyethylene or vinyl plastic extruded over each tube; or bundled bare tubes with 1/16" minimum polyethylene or vinyl plastic sheath extruded over all. Dekoron Coated Instrument Tubing or Dekoron Metl-Cor or equivalent.

Tubing Minimum Wall Thickness for 500 psi Working Pressure:

<table>
<thead>
<tr>
<th>Size</th>
<th>Wall Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/8&quot;</td>
<td>OD x .030&quot; Wall</td>
</tr>
<tr>
<td>3/16&quot;</td>
<td>OD x .030&quot; Wall</td>
</tr>
<tr>
<td>1/4&quot;</td>
<td>OD x .030&quot; Wall</td>
</tr>
<tr>
<td>5/16&quot;</td>
<td>OD x .032&quot; Wall</td>
</tr>
<tr>
<td>3/8&quot;</td>
<td>OD x .032&quot; Wall</td>
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<td>1/2&quot;</td>
<td>OD x .035&quot; Wall</td>
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<tr>
<td>5/8&quot;</td>
<td>OD x .049&quot; Wall</td>
</tr>
<tr>
<td>3/4&quot;</td>
<td>OD x .049&quot; Wall</td>
</tr>
</tbody>
</table>

Test: Hydrostatic test at 1.5 times working pressure. Use pressure drop method for leak detection. (Dry with oil-free air or nitrogen if moisture is a problem.) See Appendix for pneumatic pressure drop test for tubing.

Cleaning: Flush with line fluid or blow out with oil-free air or nitrogen.

Revised 7-21-61
Service: Water, Oil, Air, Condensate, Argon, CO₂, Nitrogen, Helium*
Pressure: 500 to 2000 psi
Temperature: 100 °F maximum

Fittings: 1. 37° Flared Type ASA B31.1
2. Socket Welded Type Parker Appliance Co.
3. Silver Brazed Socket Type ASA B31.1

Fittings Material: 1. Bar stock or forged steel, cadmium or zinc plated.
2. Bar stock or forged stainless steel - Type 316

Tubing: 1. Seamless copper tubing, per ASTM B75 may be used up to a maximum pressure of 1100 psi.
2. Seamless stainless steel tubing ASTM Spec A213 Grade TP 304
3. Soft annealed seamless carbon steel tubing per SAE Specifications. (Not recommended for condensate or water.)

Tubing Wall Minimum Thickness

<table>
<thead>
<tr>
<th>Steel &amp; Stainless Steel Tubing</th>
<th>Copper Tubing (1100 psi maximum)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/8&quot; OD x .032&quot; Wall</td>
<td>1/8&quot; OD x .030&quot; Wall</td>
</tr>
<tr>
<td>3/16&quot; OD x .032&quot; Wall</td>
<td>3/16&quot; OD x .030&quot; Wall</td>
</tr>
<tr>
<td>1/4&quot; OD x .035&quot; Wall</td>
<td>1/4&quot; OD x .035&quot; Wall</td>
</tr>
<tr>
<td>5/16&quot; OD x .049&quot; Wall</td>
<td>5/16&quot; OD x .035&quot; Wall</td>
</tr>
<tr>
<td>3/8&quot; OD x .049&quot; Wall</td>
<td>3/8&quot; OD x .035&quot; Wall</td>
</tr>
<tr>
<td>1/2&quot; OD x .065&quot; Wall</td>
<td>1/2&quot; OD x .049&quot; Wall</td>
</tr>
<tr>
<td>5/8&quot; OD x .083&quot; Wall</td>
<td>5/8&quot; OD x .049&quot; Wall</td>
</tr>
<tr>
<td>3/4&quot; OD x .095&quot; Wall</td>
<td>3/4&quot; OD x .049&quot; Wall</td>
</tr>
</tbody>
</table>

Minimum recommended wall thickness for socket welded tubing is .065".

Test: Hydrostatic test at 1.5 times working pressure. Use pressure drop method for leak detection. (Dry with oil-free air or nitrogen if moisture is a problem.) See Appendix for a pneumatic pressure drop test for tubing.

Cleaning: Flush with line fluid or blow out with oil-free air or nitrogen.

*For helium, use socket welded fittings throughout.

Revised 7-21-61
Service: Water, Air, Oil, Condensate, Argon, CO₂, Helium, * Nitrogen
Pressure: 500 to 3500 psi maximum
Temperature: 700 F maximum

Fittings:
1. 37° Flared Type
2. Socket Welded Type

Material:
1. Bar Stock or forged steel, cadmium, or zinc plated
2. Bar Stock or forged stainless steel - Type 316

Tubing:
1. Seamless stainless steel tubing ASTM Spec A213
   Grade TP 304
2. Soft annealed seamless carbon steel tubing per SAE
   Specifications. (Not recommended for water or condensate.)

Tubing Wall Minimum Thickness:

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Wall Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/8&quot;</td>
<td>.032&quot;</td>
</tr>
<tr>
<td>3/16&quot;</td>
<td>.032&quot;</td>
</tr>
<tr>
<td>1/4&quot;</td>
<td>.035&quot;</td>
</tr>
<tr>
<td>5/16&quot;</td>
<td>.049&quot;</td>
</tr>
<tr>
<td>3/8&quot;</td>
<td>.049&quot;</td>
</tr>
<tr>
<td>1/2&quot;</td>
<td>.065&quot;</td>
</tr>
<tr>
<td>5/8&quot;</td>
<td>.083&quot;</td>
</tr>
<tr>
<td>3/4&quot;</td>
<td>.095&quot;</td>
</tr>
</tbody>
</table>

Minimum recommended wall thickness for socket welded tubing is .065".

Test:
Hydrostatic test at 1.5 times working pressure. Use pressure drop method for leak detection. (Dry with oil-free air or nitrogen if moisture is a problem.) See Appendix for a pneumatic pressure drop test for tubing.

Cleaning: Flush with line fluid or blow out with oil-free air or nitrogen.

*For helium, use socket welded fittings throughout.

Revised 7-21-61
APPENDIX

APPARATUS FOR A PNEUMATIC PRESSURE DROP TEST FOR TUBING

(This sketch and operation instructions should be incorporated into the drawings or specifications for individual jobs, where applicable. The allowable rate of pressure drop should be specified.)

![Diagram of apparatus for pneumatic pressure drop test for tubing]

**Item** | Qty | Description
---|---|---
1 | 1 | Press Red. Valve Conoflow H-20
2 | 1 | \( \frac{3}{4} \)" gage, 0-20 psi
3 | 2 | \( \frac{1}{4} \)" brass globe valve
4 | 1 | Adapter to connect to line under test
5 | 1 | Cap or plug for line under test
6 | 1 | 2\( \frac{1}{2} \)" U-tube manometer
7 | 1 | Seal trap

**OPERATION:**

1. Open valve B
2. Open valve A
3. Regulate PRV until line under test, and manometer, are at 15 psi.
4. Close valve B
5. Observe manometer for rise in seal fluid on side connected to line under test. An unbalance of manometer fluid indicates a leak.
6. Close valve A
7. Open valve B before disconnecting line to prevent blowing manometer fluid.

New 7-21-61
DG-402-I

GUIDE

for

SELECTION OF PNEUMATIC CONTROL VALVES
GUIDE FOR SELECTION OF PNEUMATIC CONTROL VALVES

I. PURPOSE

The Guide for Selection of Pneumatic Control Valves is intended to serve as a guide for design engineers, plant maintenance engineers, foremen, and others who specify or use control valves. The guide cannot be substituted for construction specifications.

Use of this guide should help the user make a more intelligent approach to valve selection. However, for final selection of type, material, and size, it is generally advisable to rely upon valve manufacturers for assistance.

II. TERMINOLOGY AND DEFINITIONS

Actuator: See Topworks.

Air-to-open: Air pressure is required to open the valve. The valve is "normally closed".

Air-to-close: Air pressure is required to close the valve. The valve is "normally open".

Angle Valve: A valve through which flow passes in the side and out the bottom.

Bellows Seal: A bellows seal is placed between valve stem and valve body to prevent leakage which might occur past conventional packing.

Body Connections: Connections into the body other than end connections. This includes the bonnet and bottom cap.

Body Material: Cast iron, steel, stainless steel, to suit the environment in which the valve will operate.

Bonnet: The valve part which joins the topworks to the valve body. It usually houses the stem packing box.

Characteristic: The relationship between flow through the valve and the valve stem travel. The plug shape determines the characteristic.

Contoured Plug: A plug shaped to give certain "characteristics", generally linear or parabolic.
Cv, Valve Coefficient: The number of U. S. gallons of water per minute that will pass through a valve at a 1.0 psi pressure drop.

Direct-Actuator: Stem pushes down on increased air.

Direct Acting: See Air-to-open.

Double-acting actuator: The actuator contains no spring. It is driven both upward and downward by air.

Double-seat: A valve with two flow paths through it.

End Connections: Connections on the valve which are used for mounting it in the pipeline. They can be screwed, flanged, or welded.

Equal Percentage Characteristic (logarithmic): At a constant pressure drop, the rate of change of flow increases at a constant rate for a unit change in lift. (If the flow through the valve is 10% at 40% lift, it will be 20% at 60% lift. 30% at 70% lift, 40% at 75% lift, etc. - see figure I).

Guiding: Bearing surfaces on the stem and sometimes the plug which hold the stem and plug in position.

Hysteresis: The difference in valve position at a given control pressure when approached from closed or open positions.

Inner Valve: See Trim.

Linear Characteristic (Parabolic): At a constant pressure drop, the percentage flow through the valve is equal to the percentage stem lift. (The flow through the valve is 50% of maximum when the valve stem has risen 50%).

Motor: See Topworks.

Normally open: The valve is open with no air pressure applied to the diaphragm.

Normally closed: The valve is closed with no air pressure applied to the diaphragm.

Offset Valve: A valve similar to the straight-through valve except the discharge is at a lower elevation than the inlet.

On-Off Valve: A valve which is intended for use only in the closed or wide open positions.

Parabolic: See Linear Characteristic.

Quick-opening Valve: A valve with beveled seats. Maximum flow is attained with slight motion of the plug. Generally used in on-off service.
Rangeability: The ability of the valve to control flow over a wide range of flows. A thirty-to-one ratio between maximum and minimum controllable flow is good. Valves with fifty-to-one ratio are available.

Regulator: See Self-acting Valve.

Reverse-actuator: Stem pushes up on increased air.

Reverse Acting: See Air-to-close

Reversible body: A valve in which the seat can be turned over to change the operation from air-to-open to air-to-close or vice versa.

Self-acting valve: A valve which is operated by the process pressure, temperature, etc. No external source of power such as air is required.

Single seat: A valve with only one flow path through it.

Straight-Through Valve: A valve, such as a common globe valve, through which flow passes in a straight line.

Superstructure: See Topworks.

Throttling Valve: A valve which is intended to control flow rather than merely turn it on or off.

Top-and-bottom guided: The valve stem is guided by sleeve bearings above and below the plug or plugs.

Topworks: The topworks is the valve actuator which generally consists of a diaphragm in a steel casing, a spring which opposes the motion of the diaphragm, a stem for moving the valve plug, and a yoke for mounting the assembly to the valve body. Sometimes referred to as the motor.

Trim: The seat ring and plug.
### III. COMMON CONTROL VALVE TYPES

<table>
<thead>
<tr>
<th>GENERAL TYPE</th>
<th>SPECIFIC TYPE</th>
<th>SERVICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single seat</td>
<td>Poppet or Bevelled</td>
<td>On-Off or low rangeability, quick opening (usually top guided only).</td>
</tr>
<tr>
<td></td>
<td>Needle ( incl. splines)</td>
<td>Very low flows. High pressure drop. Tight shut-off.</td>
</tr>
<tr>
<td></td>
<td>Plug Cock</td>
<td>Poor flow characteristic for throttling service, requires large torque, line size when full open.</td>
</tr>
<tr>
<td></td>
<td>V-Port Plug</td>
<td>Tight shut-off. Satisfactory control where upstream pressure is constant.</td>
</tr>
<tr>
<td></td>
<td>Contoured Plug</td>
<td>Tight shut-off. Satisfactory control where upstream pressure is constant.</td>
</tr>
<tr>
<td>Double Seat</td>
<td>Piston ( no seats)</td>
<td>Rarely used, (since plugs are equal area, valve is theoretically perfectly balanced). Not tight shut-off.</td>
</tr>
<tr>
<td>(Balanced)</td>
<td>V-Port Plug</td>
<td>Low to moderate pressure drop. Not tight shut-off. Better control than similar single-seated valve.</td>
</tr>
<tr>
<td></td>
<td>Contoured Plug</td>
<td>Low to moderate pressure drop. Not tight shut-off. Better control than similar single-seated valve.</td>
</tr>
<tr>
<td>Venturi Throat</td>
<td></td>
<td>Self cleaning</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Viscous fluids</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slurries</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dirty Solutions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Large capacity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tight Shut-off</td>
</tr>
<tr>
<td>Three Way</td>
<td></td>
<td>Blending or by-pass diversion (By-pass valve generally has quick opening plug).</td>
</tr>
<tr>
<td>Butterfly</td>
<td></td>
<td>Low pressure drop</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High flow</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Not tight shut-off</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Requires large torque at high pressure drop.</td>
</tr>
<tr>
<td>Saunders Patent</td>
<td></td>
<td>High flow</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Corrosion resistance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tight shut-off</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low pressure drop</td>
</tr>
<tr>
<td>Angle</td>
<td></td>
<td>For flashing(vaporizing) fluids</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Suspended solids</td>
</tr>
<tr>
<td>Offset</td>
<td></td>
<td>For installations where easy draining is required.</td>
</tr>
</tbody>
</table>
IV. INNER VALVES

The contour of the valve plug and seat assembly determines the valve "characteristics" or the rate of flow through the valve at various open positions and differential pressures. The three most common characterized valve types are the quick opening, the linear or parabolic, and the equal percentage or logarithmic.

Quick Opening plugs can have several different shapes but they all give large valve opening with short stem travel. The valve may be either single or double-seated. The quick opening plug has poor throttling action due to the fact that extremely small disturbances such as motion of the stem, or change in upstream or downstream pressure, will give a large change in flow. Therefore, its use is generally limited to on-off service. However, it is used in gas regulators where rapid response is required with slight actuator motion.

Linear plugs are used where a large percentage of the pressure drop in a system is developed across the valve or when maximum capacity of the valve is required. The plug may be single or double-seated and may have various shapes. A given stem movement will change the flow an equal amount throughout the stroke of the plug.

Equal Percentage plugs can also have different shapes and can be single or double-seated. The valve has high lift for low flow with increasing flow per unit lift as the valve opens. This makes it valuable for applications where most of the system pressure loss is across the valve at low flow, and less pressure loss is across the valve at higher flows.
V. SELECTION OF VALVE CHARACTERISTIC

While the quick opening valve is generally selected for on-off or extremely simple control problems, the choice between linear or equal percentage characteristics for other problems is not easily made. Valve manufacturers indicate that the equal percentage valve with V-ports, top and bottom guided, is most generally favored by users. The equal percentage valve gives good control over a wide range of flow and pressure changes. Therefore, it is sometimes selected when actual operating conditions cannot be determined.

VI. SELECTION OF BODY TYPE (single-seated vs. double-seated)

Double-seated valves are generally used for flow control because of their semi-balanced feature, especially where high pressure drops are encountered. They are not satisfactory where tight shut-off is required.

Single-seated valves are also used for flow control where tight shut-off is required, or where the flow is extremely low.
VII. VALVE SIZING

The valve coefficient, \( C_v \), is the flow of U. S. gallons of water which will pass through the valve in one minute with 1.0 psi differential pressure across the valve. By reducing a specific control valve problem to \( C_v \) required, the proper size valve can be obtained. \( C_v \) is a more reliable criteria for valve sizing than the actual port size because the contour of the valve influences its capacity. This means that valves of the same size may have different capacity.

Formulas For Calculating \( C_v \)

\[
\text{Liquid: } C_v = \frac{\text{GPM}}{\sqrt{\frac{G}{dP}}}
\]

\[
\text{Steam: } C_v = 0.0159 \frac{W}{\sqrt{\frac{V}{dP}}}
\]

\[
\text{Gas: } C_v = 0.000735 \frac{Q}{\sqrt{\frac{(460+F)G}{dP+P}}}
\]

- **GPM** = U.S. gallons per minute
- **W** = Pounds of steam per hour
- **Q** = Cubic feet of gas per hour at 60 °F and 14.7 psia
- **\( C_v \)** = Valve flow coefficient
- **\( G \)** = Specific Gravity (For liquids - water = 1.0)
  (For gases - air = 1.0)
- **\( V \)** = Specific volume of inlet steam
- **\( F \)** = Inlet gas temperature, °F
- **\( dP \)** = Pressure drop across valve in psi. Not to be greater than half the absolute inlet pressure for steam or gas.
- **\( P \)** = Inlet pressure in psia.

The valve manufacturer will supply a valve with a \( C_v \) equal to or greater than the calculated \( C_v \).

NOTE: For convenient charts, sample sizing calculations, and slide rules for determining the \( C_v \) for a specific problem, see:

- Hammel-Dahl Bulletin No. 200-A
- Fisher Governor Co. Bulletins No. AL-3 and AL-4
- Mason-Neilan Valve Slide Rule
- Foxboro Co. Valve Slide Rule & Instruction Book
- Minneapolis-Honeywell Valve Slide Rule & Catalog C800-1, "Process Control Valves"

VIII. DIMENSIONS

For face to face dimensions of flanged control valve bodies see Instrument Society of America (ISA) Tentative Recommended Practice RP 4.1, Uniform Face to Face Dimensions for Flanged Control Valves.
IX. SPECIFICATIONS FOR CONTROL VALVES

Specifications for control valves should be made as complete as possible to lessen chances of error, to forestall delays caused by vendor or contractor correspondence requesting additional information, and to permit competitive bidding. Instrument Society of America Tentative Recommended Practice, ISA RP 20.1, "Specification Forms for Instruments, Gages, Thermocouples, Orifice Plates and Flanges, Control Valves, and Pressure Safety Valves," contains a comprehensive specification form for control valves. It is recommended that this form be used as a check list for preparation of control valve specifications.
DG-403-I

GUIDE

for

SELECTION OF PROCESS CONTROL INSTRUMENTS
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<td>2</td>
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<td>26</td>
</tr>
<tr>
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<td>30</td>
</tr>
</tbody>
</table>
I. PURPOSE

The purpose of this Guide is to provide a brief description of the general automatic control problem and the types of control equipment available for application to various process control problems. It is intended as a guide to the proper application of commercial process control instruments.

II. INTRODUCTION

In the automatic control of process variables such as temperature, flow or pressure, for example, it is usually desired to maintain the process variable at a given set point under varying load conditions. The set point may be fixed or it may vary in accordance with a secondary input signal (programmer or master controller). A block diagram of the control system might be as follows:

![Block Diagram of Control System](image)

The difference between the set point and measured variable signals, known as the "deviation", provides an error signal $e$ to the controller, which acts to reduce the deviation. In Fig. 1 the control mechanism, such as a valve, is included as part of the process. If it were not for time lags involved in the system, the problem would simply be one of using a controlling mechanism with sufficient "gain" or amplification to reduce the deviation to an acceptable value. Infinite amplification would result in theoretically perfect control. Time lags are the result of energy storage, and are present in all physical systems. The effect of time lags is to cause system instability (oscillation) at high controller gains. To prevent instability it is therefore necessary to use less controller error amplification, and the result is imperfect control. The degree of control accuracy obtainable is thus a definite function of the process time lags involved.

A wide variety of types of control instruments is available. The controller may consist of a simple switch or it may be a complex amplifying device whose output is proportional to the deviation, one or more of its time rates of change (derivatives) and its time integral. The latter types have adjustable time responses which may be used to at least partially compensate for process time lags.
The type of controller to be selected depends largely upon the following considerations:

1. The time characteristics of the process (its response to disturbances at various points in the system).

2. The methods of operating the process (manual or automatic startup of batch or discontinuous processes, or expected changes in setpoints or load conditions of continuous processes, etc.).

3. The required accuracy (maximum allowable continuous deviation from the setpoint).

4. The relative importance of short-time (transient) deviations on product quality.

5. The effects of continuous cycling on product quality or on the control of related process variables.

6. Reliability — The estimated costs of shutdown or inferior product quality due to equipment malfunction.

7. Economic relationships between costs of instrument installation and maintenance and the desired product quality.

As a general rule of thumb, control instruments should be kept as simple as possible consistent with the required performance. Increased complexity usually decreases overall reliability and increases costs. Each application must, however, be carefully evaluated to determine the optimum selection.

III. GENERAL CONTROLLER TYPES

For purposes of this Guide it will be convenient to divide existing control instruments into two general types:

1. Type I control instruments will consist of those devices which actuate a switching mechanism and modulate the process energy supply (steam flow, electrical current, etc.) in predetermined steps.

2. Type II control instruments will consist of those devices which produce a continuous output signal, this signal being related to the deviation of the measured variable from the set point by some predetermined function of time or a constant.

Some cases arise where the line of demarcation between Type I and Type II controllers is not clearly defined. For the most part, however, this division will simplify the following descriptions.
Type I control devices may range from a simple relay, designed to actuate at a predetermined signal level, to a 3-mode* controller (for example, Leeds & Northrup Series 60 Duration-Adjusting-Type controller). In its simplest form the controller switches the control agent from zero to its maximum value as the controlled variable crosses the setpoint. As a general rule, Type I controllers are less expensive than Type II controllers of equal quality and flexibility. Conversely, they can be used only on processes where one or more of the following relationships exist:

a. The reaction time of the process (or process period) is large compared to the cycling period of the controller.

b. Cycling of the process variable is permitted. The amplitude of the oscillation will depend on the relationship stated in "a".

Table I lists some of the more common forms of Type I controllers along with some representative commercial products. Listing of these particular examples does not imply that they are superior to other manufacturers' products. One manufacturer may make only one or all of the forms shown.

* A controller whose average output is proportional to the magnitude, the time integral and the time rate of change of the process deviation.
### TABLE I. TYPE I CONTROLLERS

<table>
<thead>
<tr>
<th>Action</th>
<th>Representative Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two-Position (fixed diff. gap)</td>
<td>Honeywell Pyr-O-Vane Series 105C4-13</td>
</tr>
<tr>
<td></td>
<td>Wheelco Model 401</td>
</tr>
<tr>
<td></td>
<td>All controllers or alarm devices using a single contact or relay, whether pneumatic,</td>
</tr>
<tr>
<td></td>
<td>hydraulic or electric.</td>
</tr>
<tr>
<td>Two-Position (variable diff. gap)</td>
<td>Honeywell Pyr-O-Vane Series 105C4-22</td>
</tr>
<tr>
<td></td>
<td>General Electric Model HP-32</td>
</tr>
<tr>
<td></td>
<td>On-off controllers using adjustable and separate &quot;on&quot; and &quot;off&quot; contacts or pneumatic</td>
</tr>
<tr>
<td></td>
<td>relays with adjustable differential gap.</td>
</tr>
<tr>
<td>Multiple Position (variable setpoints)</td>
<td>Honeywell Pyr-O-Vane Series 105C4-13</td>
</tr>
<tr>
<td></td>
<td>General Electric HP-33</td>
</tr>
<tr>
<td></td>
<td>Bristol Free Vane Model OV536</td>
</tr>
<tr>
<td>Time Proportioning (Narrow Band)</td>
<td>Honeywell Pyr-O-Vane Series 105C4-25</td>
</tr>
<tr>
<td></td>
<td>Wheelco Model 402</td>
</tr>
<tr>
<td>Time Proportioning (Wide band plus Reset)</td>
<td>Honeywell Electro-Pulse</td>
</tr>
<tr>
<td></td>
<td>Bristol-Beck Putmo</td>
</tr>
<tr>
<td>Time Proportioning (wide band + reset + rate)</td>
<td>Leeds &amp; Northrup Series 60</td>
</tr>
</tbody>
</table>
Type II Control Instruments

Type II Controllers are control devices which provide a continuous control signal to a proportioning type of final control element, such as a diaphragm operated valve. They may, however, be included as part of the final control element, as in a self-actuated temperature control valve. The signal medium may be electric, pneumatic, hydraulic, mechanical or combinations of these.

Type II Controllers must be used on processes which have fast reaction times and appreciable time lags, and in which cycling of the process variable is not permissible. They are desirable in all processes where large and/or expensive final control elements are used and where excessive maintenance costs due to final control element wear would be experienced with switching devices.

The output signal of a Type II controller varies as some continuous function of the process deviation, or error input. The proper choice of control function, or control mode, requires some knowledge of the process characteristics and the types and severity of disturbances likely to be encountered. In general, the control modes are selected to compensate for, or cancel, the large transfer lags in the process.

IV. DESCRIPTIONS OF CONTROL ACTIONS (MODES)

There are in general use only four basic types of control actions. Many variations of these basic types are available and all proprietary designs fall short of the theoretical performance to be described below. The importance of these practical limitations depends on the required control accuracy, the type of process to be controlled, and/or the significance placed on calibrated controller adjustments by the operating or maintenance personnel.

The four control actions to be described here are:

1. Two-position
2. Proportional
3. Reset (Integral)
4. Rate (Derivative)

The first two modes are frequently used alone. Mode 3 is generally used with proportional action but may be used alone. Mode 4 must be used with Proportional or Reset (Integral) action in order that a specified setpoint be maintained. In all known commercial controllers, Rate action is combined with Proportional action. The 3-mode controller referred to in Section III combines Proportional, Reset and Rate actions.

A. Two-Position Action

Two-position action is accomplished in a control instrument when the controller response (signal) is always at one of two possible values. Its most common form is that of a switch actuated by a mechanical motion which is proportional to the measured variable. The switch mechanism is set to trip at the desired setpoint. The control agent (electrical power, steam supply, etc.) is thus switched between two predetermined values. When these two values are the zero and maximum values of the control agent, simple "on-off" control is obtained. These controllers are, therefore, in the Type I classification. For many processes it is desirable to switch
between two intermediate values of control agent to reduce the amplitude of oscillation obtained with this type of control.

The majority of available switching devices possess a differential gap, fixed or adjustable. As the measured variable increases through the set point the switching mechanism is actuated and, depending on the magnitude of the process time lags, the measured variable will eventually begin to decrease. The measured variable must now decrease to a value less than the setpoint before switching action occurs in the opposite direction. The distance between the two switching points is the differential gap, and is usually expressed as a percentage of controller scale. See Figure 2.
Instruments with adjustable differential gap normally have the set point index aligned with the upper edge of the gap. However, it may be adjustable or specified otherwise in some cases.

Three-position control is an extension of the two-position concept. It allows the use of three predetermined values of control agent. For processes which have only small load changes the intermediate value of the control agent may be set to equal the average demand and the remaining two positions are then used to correct for load changes. Closer control of the measured variable is thus obtained using three-position control. A typical arrangement may be as shown in Figure 3.
There are many variations to the basic control actions described here. Manufacturer's literature and terminology should be critically examined to determine the actual control actions to be obtained from the manufacturer's product being considered. The types of processes on which two position (or three position) control may be used successfully will be summarized in Section VIII.

B. Proportional Action

Proportional action is that control action in which the controller output response is proportional to the magnitude of the deviation of the measured variable from the setpoint. The relationship between the controller response \( M_C \) and the deviation \( e \) is:

\[
M_C = K_p e + M_{CO} \quad (1)
\]

Where: \( M_{CO} \) is the value of \( M_C \) for zero deviation

\( K_p \) is the controller gain or amplification.

The most commonly used term for proportional action (in the process control field) is Proportional Band. It is defined as the change in measured variable (in percentage of controller scale) required to change the controller response \( M_C \) from one limit to the other (3 to 15 psig in most pneumatic systems). In terms of Equation (1):

\[
\text{Proportional Band} = \frac{100}{K_p} \quad (2)
\]

Figure 4 illustrates the action of a proportional controller.
Theoretically, the response of a proportional controller is independent of frequency and has zero phase shift. Practically, few commercial controllers provide constant gain (proportional band) and zero phase shift for deviation signal components in excess of 1 cycle per second.

In controllers providing only proportional action there is a definite controller response for each deviation. If the deviation is zero, the controller response will always be 50% of maximum. Therefore, a sustained deviation (offset) will be experienced for all load conditions requiring anything but a 50% controller response. The amount of this sustained deviation will be inversely proportional to the Proportional Band setting (in a linear system).

C. Reset Action

Reset action is an integrating action which produces a change in the controller response $M_C$ proportional to the time integral of the deviation $e$:

$$M_C = K_I \int_0^t e \, dt + M_{CO}$$  \hspace{1cm} (3)

Where: $K_I$ is the Reset time constant, $M_{CO}$ is the controller response for zero deviation.

The rate of change of the controller response is now proportional to the deviation since, from equation (3):

$$\frac{dM_C}{dt} = K_I e$$  \hspace{1cm} (4)

It can be seen that as long as a deviation exists the controller response will change (unless a limit is reached before the deviation is reduced to zero). Therefore, Reset action can be used to eliminate the "offset" experienced with proportional controllers. The reset response to three different types of deviations is illustrated below:

- **STEP INPUT SIGNAL**
  - $e = k$
  - $K_I = 1$
  - $M_C = K_I t$

- **RAMP INPUT SIGNAL**
  - $e = Kt$
  - $K_I = 2$
  - $M_C = K_I t^2$
In the practical case where a deviation occurs and is reduced to zero by controller action, the total change in controller response due to reset action $M_{cI}$, is proportional to the area under the deviation curve. See Fig. 5c.

The frequency response of a device producing theoretical reset action is as shown in Fig. 5d. It is shown that corrective action will be inversely proportional to frequency. The phase shift is constant at $-90^\circ$ (lagging angle). Zero frequency corresponds to the steady state process condition. Since, with reset action, maximum controller gain is obtained under steady process conditions, the steady state deviation is reduced to a minimum value (usually less than plus or minus 5% of the proportional band width).

In practical controllers, reset action units are usually calibrated either in repeats per minute or in minutes per repeat. In the latter, a sustained deviation should cause the controller response to change by an amount equal to that which would be provided by a proportional controller, in the time specified on the calibrated dial. The actual response may be in error because of interaction between the various control mode settings.

D. Rate Action

Rate action is a derivative action which produces a change in the controller response $M_c$ proportional to the rate of change of the deviation $e$:

$$M_c = K_d \frac{de}{dt} \quad (5)$$
Since the controller response would always be zero unless the process variable were changing, it is necessary to combine Rate action with either Proportional or Reset action in a practical control instrument.

Rate action has a stabilizing effect on the control system (when used properly) since it provides a maximum correction when the controlled variable is changing rapidly and minimum correction as the controlled variable begins to stabilize at any level. The response to several types of signals is given in Figure 6.

The frequency response of a device producing pure rate action is as shown in Fig. 6 (d). Corrective action is directly proportional to frequency while the phase shift is fixed at +90 degrees (leading angle).

In practical controllers, rate action is always combined with proportional action. The unit for $K_p$ is time. Refer to Section E for a more complete definition of the combined proportional plus rate response.
FIGURE 6
RATE ACTION
Controller actions may be combined to provide a wide variety of controller responses. Parallel combination is desirable since the various control actions are added and the adjustments tend to be independent of each other. In practice, most controllers are plagued with "interaction factors" which tend to make the actual controller response different from that indicated by the calibrated dial settings. If, as is usually the case, the controller adjustments are optimized after the process is started up, the effects of interaction between the various control modes may not be seriously objectionable. Mention should, however, be made of the performance limitations imposed by the interaction factors inherent in some controller designs, even though the ranges of dial settings are identical to other controllers being considered.

Where difficult processes are involved and where an analytical approach to the problem is being attempted, it is essential to at least know how the control modes are interrelated. This information can be obtained using the frequency response method. Actual frequency response curves on the control instruments to be used will show the effects of interaction as well as other characteristics such as dead space, hysteresis, etc.

In the paragraphs to follow it is assumed that theoretically perfect control actions are added to obtain the combined responses. Deviations from this condition in an actual problem will require some modification of controller dial settings but the general type of control instrument required for a given process should normally not be changed.

The defining equations for the most popular combined control actions are tabulated below:

**Proportional Plus Rate**

\[ M_c = K_p e + K_p K_D \frac{de}{dt} + M_{co} \]  \hspace{1cm} (6)

**Proportional Plus Reset**

\[ M_c = K_p e + K_p K_I \int e \, dt + M_{co} \]  \hspace{1cm} (7)

**Proportional Plus Reset Plus Rate**

\[ M_c = K_p e + K_p K_I \int e \, dt + K_p K_D \frac{de}{dt} + M_{co} \]  \hspace{1cm} (8)

Where
- \( M_c \) = controller time response
- \( M_{co} \) = controller steady state response for zero deviation
- \( e \) = deviation from setpoint (error)
- \( K_p \) = Proportional constant (gain)
- \( K_I \) = Reset time constant
- \( K_D \) = Rate time constant
The various control responses to a ramp signal are compared in Figure 7. Figure 8 compares the frequency response characteristics. It should be explained that practical controllers are usually not capable of providing the 90 degree phase lead shown in Figure 8. Most proprietary controllers are limited to a phase lead of less than sixty (60) degrees. The amount of phase lead obtainable also varies with the process period and is further limited at short periods (high frequencies) by the high frequency response of the controller.
Figure 7
Combined response of various control actions
Figure 8

Frequency response of various combined control actions.
V. PROCESS CHARACTERISTICS

The performance required of a control system is dictated by the dynamic characteristics of the process to be controlled, the type and magnitude of disturbances to be expected, and the required control accuracy. Exact analysis of most processes is difficult, if not impossible. However, by applying relatively simple concepts, the characteristics of many processes can be estimated with sufficient accuracy to allow proper selection of the control system components. The control modes of most process controllers are adjustable over a relatively wide range, thus reducing the accuracy required in the analysis of the processes.

To simplify analysis, it is convenient to represent a process by one or more "blocks" or "elements" with a specified output/input relationship (transfer functions). Using the nomenclature outlined in Figure 1:

\[ G = \frac{c}{r} \]  

(Fig. 9 Process Element)

The dynamics of most processes can be estimated by considering them to be made up of combinations of the following basic elements:

1. Proportional Element
2. Capacitance element (Integrating element)
3. Time constant element
4. Dead-time lag element

The dynamic characteristics of these process elements are shown in Table II.
### Table II

<table>
<thead>
<tr>
<th>Type of Element</th>
<th>Describing Equation</th>
<th>Proportional</th>
<th>Capacitance</th>
<th>Time Constant</th>
<th>Dead-Time Lag</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportional</td>
<td>$c = Kr$</td>
<td>$c = \frac{dc}{dt} = r$</td>
<td>$T \frac{dc}{dt} + c = r$</td>
<td>$c(t) = r(t-L)$</td>
<td></td>
</tr>
<tr>
<td>Transfer Function</td>
<td>$G(s) = \frac{C}{r}$</td>
<td>$G(s) = \frac{1}{C_s}$</td>
<td>$G(s) = \frac{1}{1 + Ts}$</td>
<td>$G(s) = e^{-Ls}$</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time Response to Step Input ($r = A$ for $t &gt; 0$)</th>
<th>Frequency Response ( r = A \sin \omega t )</th>
<th>Physical Electrical Analog</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="slope.png" alt="Slope Diagram" /> ( \text{slope} = \frac{A}{C} )</td>
<td><img src="gain.png" alt="Gain vs Frequency" /> ( \log \omega \rightarrow 0 )</td>
<td>$e_o = e = Cr$</td>
</tr>
<tr>
<td><img src="gain-phase.png" alt="Gain vs Phase Lag" /> ( \text{Phase Lag} )</td>
<td><img src="phase.png" alt="Phase Lag vs Gain" /> ( \text{Gain} )</td>
<td>$e_o = c = \frac{1}{\omega} \int r dt$</td>
</tr>
<tr>
<td><img src="gain-phase.png" alt="Gain vs Phase Lag" /> ( \text{Phase Lag} )</td>
<td><img src="phase.png" alt="Phase Lag vs Gain" /> ( \text{Gain} )</td>
<td>$e_o = c = r(1 - e^{-\frac{t}{RC}})$</td>
</tr>
<tr>
<td><img src="gain-phase.png" alt="Gain vs Phase Lag" /> ( \text{Phase Lag} )</td>
<td><img src="phase.png" alt="Phase Lag vs Gain" /> ( \text{Gain} )</td>
<td>$e_o(t) = c(t) = r(t-L)$</td>
</tr>
</tbody>
</table>

Where:
- $c =$ Output Variable
- $r =$ Input Variable
- $C =$ Capacitance
- $R =$ Resistance
- $T =$ Time Constant $= RC$
- $E =$ Electrical Voltage
- $T =$ Time
- $S =$ Differential Operator $\left( \frac{d}{dt} \right)$
- $L =$ Process Lag
- $\omega =$ Angular Frequency
- $G(s) =$ Transfer Function (Func. of $s$)
- $i =$ Electrical Current

**Diagram:**
- Physical Electrical Analog
- Electrical Circuit Diagrams

**Diagram:**
- Time Response to Step Input
- Frequency Response

**Diagram:**
- Transfer Function Graphs
The proportional element represents any process element or device in which the ratio of output to input is not time dependent. Electrical resistance, flow resistance, thermal resistance, spring deflection and amplifying devices are examples of proportional elements.

The capacitance element represents any process which is capable of storing energy. Electric capacitance, thermal capacitance, and the rate of change of liquid volume (or weight) with respect to tank liquid level are examples of capacitance elements.

The time constant element is actually a combination of a proportional (resistance) element and a capacitance element in series, with the output being taken across the capacitance element. An important difference between the capacitance and time constant elements is that the latter exhibit self-regulation, i.e., the output tends to level out at a new equilibrium point after a change in input. The capacitance element stores energy at a rate which is proportional to the magnitude of the input. Its output is, therefore, continually changing as long as there is an input.

Calculation of the time constant requires a determination of the "R" and "C" elements of a process.
The general relationships are stated below:

\[ R = \frac{dP}{dq} = \frac{\text{change of potential}}{\text{change of flow}} \]  \hspace{1cm} (10) \\
\[ C = \frac{dQ}{dP} = \frac{\text{change of quantity}}{\text{change of potential}} \]  \hspace{1cm} (11) \\
\[ T = RC = \frac{dP}{dq} \times \frac{dQ}{dP} = \frac{dQ}{dq} = \frac{\text{change of quantity}}{\text{flow rate}} \]  \hspace{1cm} (12)

Where:

- \( R \) = resistance element
- \( C \) = capacitance element
- \( P \) = Process potential (electric voltage, gas pressure, liquid head, etc.)
- \( Q \) = Process quantity (liquid weight, BTU's of heat, electric charge)
- \( q \) = Process flow rate (fluid flow, heat flow, electric current)

For example, in a liquid flow process, assuming flow velocity to be in the turbulent range:

\[ \gamma = KA \ 2g \ (h_1 - h_2) \]  \hspace{1cm} (13)

Where: \( K \) = flow coefficient

\[ A = \text{Area of restriction, } ft^2 \]
\[ g = \text{acceleration constant } ft/sec^2 \]
\[ h = \text{liquid head, } ft. \]
\[ h_1 - h_2 = \text{pressure drop across restriction} \]
\[ q = \text{flow rate, } ft^3/sec. \]

Then:

\[ R = \frac{dh}{dc} = \frac{q}{gK^2A^2} = 2 \frac{(h_1 - h_2)}{q} \text{ sec/ft}^2 \]  \hspace{1cm} (14)
NOTE: (The magnitude of \( R \) is dependent on the flow rate and must be evaluated at the process flow rate under consideration).

If the liquid flows into a cylindrical tank having a cross-sectional area of \( A_t \) square feet, the liquid head in the tank will be related to the volume of liquid in the tank as follows:

\[
dQ = A_t \, dh \quad \text{(assuming constant fluid density)} \tag{15}
\]

Then:

\[
C = \frac{dQ}{dp} = \frac{dQ}{dh} = A_t \, ft^2 \tag{16}
\]

The time constant may then be found from equations (14) and (16):

\[
T = RC = \frac{2(h_1 - h_2)}{q} \times A_t = \frac{2A_t}{q} (h_1 - h_2) \tag{17}
\]

where the differential head \( (h_1 - h_2) \) is evaluated at a flow rate, \( q \), chosen near the expected operating point.

Calculation of the \( R \) and \( C \) components of other processes may be simplified by referring to the analogies given in Table III.

### TABLE III.

Dimensions of Process Characteristics

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Electrical</th>
<th>Thermal</th>
<th>Liquid</th>
<th>Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential</td>
<td>coulomb</td>
<td>Btu</td>
<td>ft³</td>
<td>lb</td>
</tr>
<tr>
<td>Time</td>
<td>volt</td>
<td>deg</td>
<td>ft</td>
<td>lb/ft²</td>
</tr>
<tr>
<td>Flow</td>
<td>sec</td>
<td>Btu/sec</td>
<td>ft³/sec</td>
<td>lb/sec</td>
</tr>
<tr>
<td>Capacitance</td>
<td>Coul./sec = amp</td>
<td>Btu/deg</td>
<td>ft³/sec</td>
<td>lb/sec</td>
</tr>
<tr>
<td>Resistance</td>
<td>volt/amp = ohm</td>
<td>deg-sec/Btu</td>
<td>sec/ft²</td>
<td>sec/ft²</td>
</tr>
</tbody>
</table>
VI. ESTIMATING THE CONTROLLABILITY OF THE PROCESS

The controllability of a process is related to its degree of stability when subjected to closed loop control. It is a factor which must be known to a moderate degree of accuracy before the controlling mechanism can be intelligently specified. Zeigler and Nichols have proposed a yardstick for estimating the controllability of a process by using the open-loop process reaction curve. The curve is usually obtained experimentally by (1) operating the process on manual control until a stable condition is reached, (2) making a known change in the manual control adjustment and recording the resultant change in the controlled variable. The result is often an S-shaped curve similar to that shown in Fig. 10.
$K =$ MAGNITUDE OF CHANGE OF THE CONTROLLED VARIABLE DUE TO A CHANGE OF $M$ UNITS OF THE MANIPULATED VARIABLE.

$L_d =$ TOTAL PURE DEAD TIME OF THE PROCESS.

$T =$ APPROXIMATE EQUIVALENT TIME CONSTANT OF THE PROCESS.

$N =$ MAXIMUM PROCESS REACTION DUE TO THE DISTURBANCE $M$.

$T =$ APPROXIMATE EQUIVALENT TIME CONSTANT OF THE PROCESS.

FIGURE 10
TYPICAL OPEN-LOOP PROCESS REACTION CURVE
The Ziegler-Nichols method assumes that the process can be closely approximated by a dead time element $L_T$ and a time constant element $T$. This approximation has been found to be reasonably accurate for a large number of processes and is used here as an aid in selecting a control instrument.

One additional quantity, the zero frequency gain of the process, is needed to predict controller settings accurately. It is obtained from Fig. 10 as the ratio $K$.

\[
\text{Zero Frequency Process Gain, } G_0 = \frac{K}{M} = \frac{\text{change in controlled variable}}{\text{change in manipulated variable}} \quad (18)
\]

Actually, the reaction rate, $N$, is used in the formulas for optimum controller settings. $N$ is proportional to $G_0$, since

\[
K = NT \quad (19)
\]
\[
\text{and } G_0 = N \frac{T}{M} \quad (20)
\]

One form of the Ziegler-Nichols formulas is given in Figure 11, following:

<table>
<thead>
<tr>
<th>Modes of Control</th>
<th>Proportional Band</th>
<th>Reset, $(R/M)$, and Rate Time, $RT$,</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportional</td>
<td>$\frac{100 NL_T}{M}$</td>
<td>$\frac{R}{M} = 0.3 \frac{L_T}{L_T}$</td>
</tr>
<tr>
<td>Proportional plus reset</td>
<td>$\frac{110 NL_T}{M}$</td>
<td>$\frac{R}{M} = 0.5 \frac{L_T}{L_T}$</td>
</tr>
<tr>
<td>Proportional plus Reset plus Rate</td>
<td>$\frac{83 NL_T}{M}$</td>
<td>$RT = 0.5 L_T$</td>
</tr>
</tbody>
</table>

Fig. 11
(Continued on following page)
Note: The control criterion for these settings is a $1/k$ decay ratio recovery (each succeeding oscillation decreases in amplitude by a factor of $k$).

**NOMENCLATURE:**

- $LT = \text{Total apparent dead time (lag) of the process in minutes.}$
- $M = \% \text{ change in control element position used in determining the process reaction curve.}$
- $N = \text{Maximum reaction rate in } \% \text{ of instrument scale per minute.}$
- $R/M = \text{repetitions per minute (reset calibration)}$
- $r_T = \text{rate time, minutes}$

**Fig. 11 - Formulas for Determining Optimum Controller Settings.**

Figure 11 is included to demonstrate that controller requirements can be estimated if the process reaction curve is available. The formula for proportional control is the most significant since it indicates the characteristics of the closed loop system before corrective or stabilizing elements are added. It thus reflects the nature of the process and allows the engineer to estimate the effects of load changes. For instance, if the formula shows that a 50% proportional band is required for stability, deviations of as much as plus or minus 25% of scale might be expected under extreme load conditions. Depending on the control accuracy required this calculation might tell the control engineer to include reset action on the controller. However, if one per cent proportional band is indicated it may be possible to control the process with a simple on-off (two-position) controller. Similarly, approximate methods of determining the need for rate action can be obtained from the process reaction curve. These are summarized in the section on "Determining Controller Requirements".

Lag ratio is defined as the ratio of the total apparent dead time $LT$, to the equivalent process time constant, $T$.

$$\text{Lag Ratio, } R = \frac{LT}{T}$$

The lag ratio provides an indication of process controllability which may be used without requiring the calculation of overall process gain. See Section VIII. Eckman, Reference 1, pp. 117-120, has tabulated formulas which can be used to determine optimum controller settings, maximum deviations and process oscillation period. The process quantities required are $LT$, $M$, $N$ and $R$. Use of these relationships is recommended on the more critical processes. On less critical processes, adequate information may be obtained from a calculation of the lag ratio, $R$.
VII. OBTAINING APPROXIMATE PROCESS REACTION CURVES BY CALCULATION

Since control equipment is usually purchased before a process is built it is not possible to determine the reaction curve experimentally in most instances. However, the characteristics of many processes can be calculated with sufficient accuracy to allow a judicious choice of control instruments. Three process characteristics are required to set up the approximate process reaction curve:

1. The total apparent dead-time lag, \( L_T \) (Process Lag).
2. The approximate equivalent time constant, \( T \).
3. The zero frequency process gain, \( G_0 \).

A. Process Lag

The process lag is made up of the pure dead-time lags plus the equivalent lag of the time constant elements.

\[
L_T = L_D + L_{eq} \tag{22}
\]

Ziegler and Nichols have proposed a method of approximating the equivalent lag of a number of time constant elements. A single time constant element has a zero lag (delay) time by definition. The equivalent lag of two cascaded time constant elements is plotted in Figure 12. If there are one or two large time constants in the process the total process lag can be approximated as follows:

1. Determine the equivalent lag of the two largest time constants from Figure 12.

2. Add a lag time equivalent to the sum of the remaining time constants. This is the total process lag, approximately.

If there are a large number of equal time constants, such as in a distillation column, a closer approximation is given by Ziegler and Nichols in Reference #6.

B. Equivalent Time Constant

The equivalent time constant, \( T \), will be somewhat greater than the largest single time constant element in the process. However, a good conservative estimate is to use the largest time constant element as \( T \) in the calculations.
Fig. 12 - Apparent Lag of Two Cascaded Time Constant Elements
C. Zero Frequency Gain

The total gain, $G_0$, is obtained by multiplying the gains of each process element under consideration. Care must be taken to use consistent units throughout the calculation. The final numerical figure for $G_0$ should be in terms of scale reading change per final control element change.

Construction of the approximate process reaction curve is shown in Figure 13. Note that the formula for proportional control given in Fig. 11 may be changed to:

$$\text{Proportional Band} = \frac{100 G_0 L T}{T}$$  \hspace{1cm} (23)

The use of frequency response methods has not been discussed because it is felt that the techniques are not familiar to the majority of engineers who would be expected to use this guide. Actually, a more accurate presentation of the process characteristics can be made using frequency response techniques with the same process information as that required to construct Figure 13. Therefore, frequency response data may be added at a later date.
**FIGURE 13**
CONSTRUCTION OF CALCULATED PROCESS REACTION CURVE
VIII. DETERMINING CONTROLLER REQUIREMENTS

Seven general considerations in the choice of a control instrument for a process were listed in the Introduction. These items should always be considered and used to evaluate or modify the approximate results obtained by analysis of the process.

For processes on which close control is not required it may be possible to estimate controller requirements without making a complete analysis of the process. Table IV gives the forms of control suited to processes of various characteristics. It should be used as a general guide only; the actual control requirements will depend on the general considerations mentioned above. In the table a single capacity process refers to a process dominated by one of its resistance-capacity pairs, while "multi-capacity" denotes a process with two or more R-C pairs of significant size.

Processes with very small capacity, such as flow processes, are successfully controlled by the proportional-speed floating (reset) mode alone or by wide-band proportional control combined with very fast reset.

The lag ratio, \( R = \frac{LT}{T} \), is a good index of process controllability for many processes. It may be obtained with less calculation than that required to estimate the process reaction curve, since it is not necessary to determine the zero-frequency process gain, \( G_0 \). As a general rule of thumb the narrowest usable proportional band will normally be about:

\[
\text{Minimum Proportional Band} = 100R = 100 \frac{LT}{T} \quad (24)
\]
<table>
<thead>
<tr>
<th>Number of process Capacities</th>
<th>Process Reaction rate</th>
<th>Process Time Lags</th>
<th>Load Changes</th>
<th>Suitable mode of control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Resistance Capacity (R-C)</td>
<td>Dead time (Transportation)</td>
<td>Size</td>
</tr>
<tr>
<td>Single</td>
<td>Slow</td>
<td>Moderate to large</td>
<td>Small</td>
<td>Any</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Moderate</td>
</tr>
<tr>
<td>Multiple</td>
<td>Slow to Moderate</td>
<td>Moderate</td>
<td>Small</td>
<td>Small</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>Any</td>
<td>Small</td>
<td>Any</td>
</tr>
<tr>
<td></td>
<td>Any</td>
<td>Any</td>
<td>Small to moderate</td>
<td>Large</td>
</tr>
<tr>
<td></td>
<td>Any</td>
<td>Any</td>
<td>Small</td>
<td>Large</td>
</tr>
<tr>
<td>Any</td>
<td>Faster than that of the control system</td>
<td>Small or nearly zero</td>
<td>Small to moderate</td>
<td>Any</td>
</tr>
</tbody>
</table>
If the process reaction curve parameters (L_T, M, N and T) are known or can be calculated with reasonable accuracy, the formulas listed in Table V may be used to determine the following:

1. **Approximate Settings for one-quarter decay ratio.**
2. **The approximate period of oscillation.**
3. **The offset.**
4. **The maximum deviation.**

It should then be a simple matter to choose the type of control instrument best suited for a particular application. However, in choosing a control instrument, the relative importance of reliability and control accuracy should be carefully considered. If there is doubt that any given control mode will provide adequate control accuracy, it is usually wise to buy the more advanced controller. The cost of additional control modes is generally small compared to the basic instrument cost. However, the added complexity of the more advanced control instrument may, in some instances, reduce its reliability. The more recent controller designs which allow convenient bypassing of the reset and rate control modes may be a logical choice in this case.

Rate action is found to be most effective on processes having one to three major time constant elements and relatively small amounts of dead time. As the dead time is increased, the improvement obtained by using rate action decreases. Here dead time refers to L_d, Fig. 10, not L_T. In fact, as the ratio of L_T to L_d increases, the benefits of rate action are increased. Since rate action amplifies high frequency components, its use may be undesirable on certain types of "noisy" processes. Flow processes often fall into this category.
### Table V - Characteristics of Various Controllers

<table>
<thead>
<tr>
<th>Type</th>
<th>Controller Settings for $1/4$ Decay Ratio</th>
<th>Closed Loop Period ( \frac{12 + 3R}{10 + 7R} )</th>
<th>Offset ( \frac{3}{3 + 4R} )</th>
<th>Maximum Deviation</th>
<th>Where:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportional</td>
<td>( K_c = \frac{M}{NL_T} \left( 1 + \frac{R}{3} \right) )</td>
<td>( P = 4L_T \left( \frac{12 + 3R}{10 + 7R} \right) )</td>
<td>( E_o = \frac{NL_T}{M} \left( \frac{3}{3 + 4R} \right) )</td>
<td>( D = 1.5 E_o )</td>
<td></td>
</tr>
<tr>
<td>Proportional plus Rate</td>
<td>( K_c = \frac{M}{NL_T} \left( \frac{5}{14} + \frac{R}{6} \right) )</td>
<td>( P = 4L_T \left( \frac{5 + 6R}{6 + 10R} \right) )</td>
<td>( E_o = \frac{NL_T}{M} \left( \frac{8}{10 + 9R} \right) )</td>
<td>( D = 1.5 E_o )</td>
<td></td>
</tr>
<tr>
<td>( T_d = L_T \left( \frac{6 - 2R}{22 + 3R} \right) )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proportional plus Reset</td>
<td>( K_c = \frac{M}{NL_T} \left( \frac{9}{10} + \frac{R}{12} \right) )</td>
<td>-</td>
<td>Zero</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>( T_i = L_T \left( \frac{30 + 3R}{9 + 20R} \right) )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proportional plus Reset plus Rate</td>
<td>( K_c = \frac{M}{NL_T} \left( \frac{4}{3} + \frac{R}{4} \right) )</td>
<td>-</td>
<td>Zero</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>( T_d = L \left( \frac{4}{11 + 2R} \right) )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( T_i = L_T \left( \frac{32 + 6R}{13 + 8R} \right) )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Where:

- \( K_c = \) Proportional gain in units of \( \frac{m}{(\text{See Fig.1})} \)
- \( T_d = \) Rate time in minutes (derivative)
- \( T_i = \) Reset time in minutes (integral)
- \( P = \) Closed Loop Period in minutes
- \( D = \) Maximum deviation
- \( e = \) error input to controller, \( K_c = \frac{m}{e} \)
- \( L_T, M, N, R = \) as defined in Figure 10

and:

- \( E_o = \) Offset in units of controlled variable
- \( E_o = \) Offset in units of \( m \) disturbance
Reset action is often available in two ranges, slow and fast actions. For fast processes, such as flow control systems using high-speed transmitters, the fast reset range should be specified to obtain rapid return to the setpoint.

Two-position controllers are frequently used in temperature, level and other control systems where the lag ratio is negligible (less than 0.1) and when cycling of the controlled variable is permissible. The amplitude and period of oscillation may be estimated from the following:

\[
A = G + \left[ K \left( \frac{M_{\text{max.}} - M_{\text{min.}}}{2 M} \right) - G \right] R
\]

\[
P = 4L_T \left[ \frac{1}{R} \tanh^{-1} \left( \frac{AM}{KM_{\text{max.}} - VM} \right) \right]
\]

Where:

- \( 2A \) = peak-to-peak amplitude of oscillation, in units of the controlled variable, \( c \).
- \( 2G \) = Total differential gap, in units of \( c \).
- \( M_{\text{max.}} \) = Maximum value of manipulated variable, \( M \).
- \( M_{\text{min.}} \) = Minimum value of manipulated variable, \( M \).
- \( P \) = Period of cycle, minutes.
- \( V \) = Setpoint, units of \( c \).

It should be realized that the accuracy of the above methods of analysis will depend on the accuracy of the process analysis. Linear processes are assumed, an assumption which is normally valid for small deviations from the setpoint. Proper use of these guides should provide the engineers with a keener insight into any control problem. There are more exact methods of analysis available, however, and it is recommended that an experienced control engineer be consulted on difficult problems requiring accurate control of the process variable.
REFERENCES:

Books


Papers


GLOSSARY OF TERMS

Capacitance is the amount of energy or material which must be added to a closed system to cause unit change in potential.

Closed loop system is a process or system in which the output is compared to the input.

Control elements comprise the portion of the control system which includes control action relating the manipulated variable to the actuating signal.

Controlled system is the body, process, or machine, a particular quantity or condition of which is to be controlled.

Controlled variable is that quantity or condition of the controlled system which is directly measured and controlled.

Corner frequency of a transfer function is the frequency at which lines asymptotic to its log-magnitude vs. log-frequency curve intersect.

Cycling is a periodic change of the controlled variable from one value to another. (Oscillation is a synonymous term.)

Dead time is a fixed interval of time between the change of an input to an element and the beginning of response to the input.

Dead zone is the largest range of values of the input variable to which an element does not respond.

Derivative action is a controller action in which there is a continuous linear relation between the derivative of the actuating signal and output signal of the controller.

Derivative time is the time difference by which the output of a proportional-derivative controller leads (is ahead of) the input when the input changes linearly with time.

Deviation is the difference at any instant between the value of the controlled variable and the set point.

Differential gap is the two-position controller adjustment: the smallest range of values through which the controlled variable must pass in order to change the output signal of the controller from maximum to minimum.

Disturbance is a signal (other than the reference input) which tends to affect the value of the controlled variable.

Floating action is that in which there is a predetermined relation between value of the controlled variable and position of a final control element.
APPENDIX I (Continued)

Frequency response of a system or element is the steady-state magnitude ratio and the difference in phase of the output with respect to a sinusoidal input.

Gain of a system or element is the ratio of magnitude of the output with respect to the magnitude of sinusoidal input.

Hysteresis is a nonlinearity in system response similar to backlash.

Integral action is that in which there is a predetermined relation between an integral function of the controlled variable and position of a final control element.

Integral time is the time required for the output of a proportional-integral controller to change an amount equal to the amount of proportional response provided by a step change of actuating signal.

Lag is the retardation or delay of one physical condition with respect to some other condition to which it is closely related.

Load change is the change in process conditions which requires a change in the average value of manipulated variable to maintain the controlled variable at the desired value.

Manipulated variable is the quantity or condition which is varied by the automatic controller so as to affect the value of controlled variable.

Offset is the steady-state deviation resulting from a change in value of the load variable.

Open-loop gain is the ratio of the change in the feedback variable and the change in deviation signal.

Open-loop process is a process in which there is no feedback from output to input.

Phase angle, referred to sinusoidally varying quantities, represents the angle between vectors representing the sinusoidal quantities.

Phase shift is a change in phase angle.

Proportional action is a controller action in which there is a continuous linear relation between value of the controlled variable and the value of the output signal of the controller.

Proportional Band, applying to proportional - position controller action, is the range of values of the controlled variable which corresponds to the full operating range of the final control element. Proportional band is commonly expressed in per cent of controller scale range or, particularly in the absence of a controller scale, in units of the controlled variable.

Proportional-Speed Floating Action is that in which there is a continuous linear relation between value of the controlled variable and rate of motion of a final control element.
**Ramp signal** is an input signal which varies linearly with time: \( f(t) = kt \).

**Rate action** is that in which there is a continuous linear relation between rate of change of the controlled variable and position of a final control element. This controller action maintains a linear relation between first derivative or rate of change of the controlled variable and position of a final control element. This identical controller action may also be considered as maintaining a linear relation between second derivative or rate of the rate of change of the controlled variable and rate of motion of the final control element.

**Rate time**: See "Derivative time".

**Reference input** is a signal established as a standard of comparison for a feedback control system by virtue of its relation to the command.

**Reset action**: Same as "Integral action".

**Reset rate** is the inverse of integral time.

**Response time** of a system or element is the time required for the output to first reach a specified value after the application of a step input or disturbance.

**Set point** is the selected reference value of controlled variable which it is desired to maintain.

The primary element is that portion of the measuring means which first either utilizes or transforms energy from the controlled medium to produce an effect in response to a change in the value of the controlled variable. The effect produced by the primary element may be a change of pressure, force, position, electrical.

**Transport lag** is a lag in response caused by two or more cascaded time constants, as opposed to transportation lag or dead time.

"**Time constant** is the time required for the output of a first-order system to range from a given value to within 36.8 per cent of the final value (or 63.2 per cent of the amount of total change) when a step change of input is made.
DG-404-I

GUIDE

for

ELECTRONIC DESIGN PRACTICE
1. PURPOSE

The intent of this guide is to provide a basic reference for those who design, specify, develop, or fabricate electronic equipment. Included is information on the following: general design considerations, safety, purchase specifications, circuit diagrams and symbols, color codes, recommended connectors and cables, relay racks and panels, and tubes.

2. GENERAL DESIGN CONSIDERATIONS

a. Provide adequate ventilation of all heat generating equipment. Individual cabinet mounted equipment dissipating over about 100 watts should be equipped with a fan. Six foot enclosed relay racks with power dissipation of over about 500 watts should be fan-cooled. A conservative figure of about 10 watts per tube may be used for estimating purposes.

   All cooling fans should be shock mounted to prevent vibration of the chassis. The cooling air intake should have filters to prevent the entrance of dust.

b. Mount all parts securely in such a location that they are easily accessible for testing and maintenance.

c. All parts and terminal boards should be numbered or otherwise identified and, where applicable, color coded.

d. All circuits should preferably be designed so that tubes and removable components are replaceable without special selection.

e. Provide test points for checking essential voltages and waveforms where terminals are not otherwise accessible.

f. Minimize the need for special tools or special assembly and adjustment procedures. If special tools are required, they should be furnished securely mounted in a convenient place. If special assembly or adjustments are required, complete instructions should be supplied.

g. Label all adjustable components, switches, pilot lights, meters, etc.

h. Seldom-used controls and adjustments should not be mounted on the front panel. Such controls should be sub-mounted so as to be adjustable from the front.
1. Potentiometers and switches should be mounted with suitable stops or with indexed holes so that they will not rotate when reasonable force is exerted against a stop. All screwdriver adjusted potentiometers shall be equipped with a shaft lock.

j. Delay lines should be constrained with clamps so as not to touch other components when moving the chassis. Connectors at elevated potentials should be insulated to prevent contact by personnel and tools.

k. Clips, sockets or diode mounting blocks should be used where possible. When it is not possible to use such devices, care should be taken when installing semi-conductors to prevent damage from excessive heat when soldering.

l. Each tube socket shall be clearly labeled with the V-number and tube type number both above and below the chassis. All other components shall be labeled with their part numbers either above or below the chassis or in both places where such is appropriate. Encapsulated items should be imprinted with their circuit diagram.

m. All soft soldered electrical connections shall be made using a tin and lead soldering mixture consisting of at least 60% tin. All solder flux shall be rosin type.

n. Parts should be mounted on terminal boards or clamped to chassis except where point to point wiring of small parts is desirable. A minimum of 3/8 inch of pigtail should be used between the body of a part and the terminal post. The pigtail should have a distinct bend, made prior to soldering the second pigtail to prevent excessive thermal and mechanical stress. Resistors should be mounted with about a 1/8 inch space between the resistor body and other adjacent items. Bends should be at least 1/8 inch from the body of the part to prevent damage to the body. Care should be taken to avoid mounting parts with a large heat dissipation close to items that may be damaged by excessive heat or whose characteristics will change with heat. For soldered joints, pigtails should not be wound around terminals more than 180°.

3. SAFETY CONSIDERATIONS

a. Every attempt shall be made to prevent personnel from coming into accidental contact with voltages in excess of 24 volts while operating the equipment.

b. Provide safety covers and warning notices for exposed potentials in excess of 24 volts at all locations inside the cabinet except the underside of the chassis.

c. Plugs and connectors, when disconnected, should not expose "hot" leads.

d. All control shafts and shaft bushings should be grounded if possible. Ungrounded shafts and bushings shall be so marked.

e. Power supplies should include a "bleeder" resistor across all capacitors to reduce the voltage to zero after the power is turned off.
4. SPECIFICATIONS

The intent of this section is to list some suggestions to be followed when writing procurement specifications for specially built electronic equipment. Such equipment is generally wholly or partially designed at Hanford.

a. The specification should include the following items:

1. Scope
   (Description of work included under this specification)

2. Description
   (Description of equipment and its purpose)

3. Applicable Documents
   (List all applicable drawings, standards, codes, military specifications, etc.).

4. Equipment Requirements
   (Describe equipment design including special materials, special fabrication techniques, special parts, etc.)

5. Testing
   (Describe required tests, data, preproduction prototypes, etc.)

b. The specification should not include words such as: "G.E.", "Engineer", "Inspector", "Vendor", "Bidder", etc. If necessary such terms should be limited to "Buyer" and "Seller".

c. The specification should not include any of the following requirements; they will be included in the Requisition:

1. Quantities
2. Services included (engineers, etc.)
3. Guarantees
4. Information required with bids
5. Inspection
6. Spare parts requirements
7. B.P.F. material
8. Operating and maintenance instructions
The following list enumerates the items that should be included on an electronic circuit diagram. Figure I shows a typical electronic circuit diagram. The purpose of this drawing is to illustrate the standard items that are listed below:

a. Pin numbers should be shown on all connectors, terminal boards and plug-in or encapsulated components such as tubes, relays, choppers, etc.

b. All components should be designated with part numbers and values where applicable, such as resistors, capacitors and inductors. Components that do not have values, such as connectors, switches, meters, relays etc., can be described where such does not cause crowding on the drawing. Where this detracts from the clarity of the drawing, however, the description of the component should be covered by the material list only.

c. Various typical notes should be included in addition to notes concerning items peculiar to the particular drawing. These should include where applicable:

1) All resistors are $\frac{1}{2}$ watt, $\pm 10\%$ unless noted.
2) All resistor values in ohms unless noted.
3) All capacitors *, volts unless noted.
4) All capacitance in microfarads unless noted.
5) $\Theta$ Denotes screw driver adjustment

d. The material list shall be included on regular circuit drawings if possible. They may be typed or printed on standard $8\frac{1}{2}$" x 11" drawing sheets and given a HAPO drawing number. In certain cases where this is not feasible, the material list should be included in the specifications.

e. Component symbolism shall be standard in accordance with the HAPO Drafting Practice Manual symbols (ASA standard).

f. Component abbreviations shall be standard in accordance with the HAPO Drafting Practice Manual.
### CAPE-1072

#### LEGEND

- **Amplifier**, manually restored drop
- **Battery, DC source**
- **Capacitor, fixed**
- **Capacitor, variable**
- **Choke connection**
- **Chassis connection**
- **Coaxial connector, female contact**
- **Coil, male contact**
- **Fuse**
- **Ground**
- **Headset**
- **Inductor, adjustable**
- **Inductor, magnetic core (choke)**
- **Jack, 2 conductor**
- **Jack, multiple conductor**
- **Lamp, indicating**
- **Lamp, neon indicating, AC type**
- **Machine, rotating (motor)**
- **Microphone**
- **Millimeter**
- **Magnet, magnetic core, shield between windings connected to frame, polarity shown**
- **Transformer, general**
- **Transformer, DC voltage regulator**
- **Tube, DC voltage regulator**
- **Tube, choke**
- **Tube, duo-triode**
- **Tube, pentode**

#### NOTES:

1. All resistors are in ohms unless noted.
2. All capacitors are in microfarads unless noted.
3. All resistors 1/2 watt; 10% unless noted.
4. All capacitors 500 volts, unless noted.
5. Items C-13, C-14, C-17, 1% silver mica capacitors.
6. Denotes screwdriver adjustment.

---

### TYPICAL CIRCUIT DIAGRAM

#### FIGURE 1

- **AC SUPPLY**
- **Speaker**
- **Switch, single pole, single throw**
- **Switch, 3 pole, single throw**
- **Thermometer**
- **Transformer, magnetic core, shield between windings connected to frame, polarity shown**
- **Tube, DC voltage regulator**
- **Tube, choke**
- **Tube, duo-triode**
- **Tube, pentode**

#### NOTIONS:

1. All resistors are in ohms unless noted.
2. All capacitors are in microfarads unless noted.
3. All resistors 1/2 watt; 10% unless noted.
4. All capacitors 500 volts, unless noted.
5. Items C-13, C-14, C-17, 1% silver mica capacitors.
6. Denotes screwdriver adjustment.
6. COLOR CODES

Wherever possible the following color code should be used on all electronic equipment:

<table>
<thead>
<tr>
<th>CIRCUIT NAME</th>
<th>COLOR</th>
<th>STANDARD ABBREVIATION</th>
<th>ALTERNATE ABBREVIATION</th>
<th>NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grounds, grounded elements, and returns</td>
<td>Black</td>
<td>Blk</td>
<td>K</td>
<td>0</td>
</tr>
<tr>
<td>Heaters or filaments off-ground</td>
<td>Brown</td>
<td>Brn</td>
<td>N</td>
<td>1</td>
</tr>
<tr>
<td>Power Supply, B /</td>
<td>Red</td>
<td>Red</td>
<td>R</td>
<td>2</td>
</tr>
<tr>
<td>Screen grids</td>
<td>Orange</td>
<td>Orn</td>
<td>O</td>
<td>3</td>
</tr>
<tr>
<td>Cathodes (emitters)</td>
<td>Yellow</td>
<td>Yel</td>
<td>Y</td>
<td>4</td>
</tr>
<tr>
<td>Control Grids (bases)</td>
<td>Green</td>
<td>Grn</td>
<td>G</td>
<td>5</td>
</tr>
<tr>
<td>Plates (collectors)</td>
<td>Blue</td>
<td>Blu</td>
<td>B</td>
<td>6</td>
</tr>
<tr>
<td>Not used</td>
<td>Violet</td>
<td>Vio</td>
<td>V</td>
<td>7</td>
</tr>
<tr>
<td>AC Power lines</td>
<td>Gray</td>
<td>Gra</td>
<td>A</td>
<td>8</td>
</tr>
<tr>
<td>Above or below ground returns, AVC, etc</td>
<td>White</td>
<td>Wht</td>
<td>W</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Gold</td>
<td>Gld</td>
<td>D</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>Silver</td>
<td>Sil</td>
<td>S</td>
<td>10%</td>
</tr>
</tbody>
</table>

7. CONNECTORS AND CABLES

7.1 CONNECTORS

Connectors should, wherever possible, be standardized to one of the types shown in Table II or Table III. Table II lists the multiconductor "Army-Navy" type connectors. Table III lists the coaxial and audio connectors.

* Standard No. GEN-101-A and REC-108-A of the EIA (Electronic Industries Association)
Table IV shows the recommended standard coaxial cables to be used in electronic equipment at HAPO. The RG-54A/U and RG-71/U cables are equipped with a polyethylene jacket. This jacket is more resistant to radiation damage than the black vinyl jacket used on the other cables. Clear polyethylene, however, should not be used out of doors because of its poor resistance to abrasion and ultra-violet light. Hanford experience shows that the polyethylene jacket should be used only where required for its radiation resistance.

The conventional black vinyl jacket on coaxial cables will, after long periods or high temperature, contaminate the dielectric. This increases the dielectric losses in the cables slightly. A low temperature, non-contaminating, black vinyl jacket is available on many cables. Included in this group are the following: RG-58C/U, RG-59B/U, RG-62A/U, and RG-11A/U. None of these cables are of the aquadag coated, low noise type.

Both the black vinyl and the polyethylene jacketed cables may be used from minus 40 degrees F to 175 degrees F. The gray vinyl used on some cables (Belden #8401) may be used from minus 10 degrees F to 175 degrees F.
### MULTI-CONDUCTOR CONNECTORS

**TABLE II**

<table>
<thead>
<tr>
<th>NUMBER OF CONDUCTORS</th>
<th>Voltage Rating (DC or Peak AC)</th>
<th>CHASSIS MALE</th>
<th>CHASSIS FEMALE</th>
<th>CABLE MALE</th>
<th>CABLE FEMALE</th>
<th>MAXIMUM Wire Size</th>
<th>CABLE CLAMP #</th>
<th>Maximum Cable Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1250</td>
<td>MS3102A-12-5P</td>
<td>MS3102A-12-5S</td>
<td>MS3106A-12-5P</td>
<td>MS3106A-12-5S</td>
<td>#12</td>
<td>AN3057-4</td>
<td>5/16&quot;</td>
</tr>
<tr>
<td>2</td>
<td>700</td>
<td>MS3102A-14S-9P</td>
<td>MS3102A-14S-9S</td>
<td>MS3106A-14S-9P</td>
<td>MS3106A-14S-9S</td>
<td>#16</td>
<td>AN3057-6</td>
<td>7/16&quot;</td>
</tr>
<tr>
<td>3</td>
<td>700</td>
<td>MS3102A-14S-1P</td>
<td>MS3102A-14S-1S</td>
<td>MS3106A-14S-1P</td>
<td>MS3106A-14S-1S</td>
<td>#16</td>
<td>AN3057-6</td>
<td>7/16&quot;</td>
</tr>
<tr>
<td>4</td>
<td>250</td>
<td>MS3102A-14S-2P</td>
<td>MS3102A-14S-2S</td>
<td>MS3106A-14S-2P</td>
<td>MS3106A-14S-2S</td>
<td>#16</td>
<td>AN3057-6</td>
<td>7/16&quot;</td>
</tr>
<tr>
<td>5</td>
<td>700</td>
<td>MS3102A-16S-8P</td>
<td>MS3102A-16S-8S</td>
<td>MS3106A-16S-8P</td>
<td>MS3106A-16S-8S</td>
<td>#16</td>
<td>AN3057-8</td>
<td>9/16&quot;</td>
</tr>
<tr>
<td>6</td>
<td>700</td>
<td>MS3102A-16S-1P</td>
<td>MS3102A-16S-1S</td>
<td>MS3106A-16S-1P</td>
<td>MS3106A-16S-1S</td>
<td>#16</td>
<td>AN3057-8</td>
<td>9/16&quot;</td>
</tr>
<tr>
<td>7</td>
<td>700</td>
<td>MS3102A-28-19P</td>
<td>MS3102A-28-19S</td>
<td>MS3106A-28-19P</td>
<td>MS3106A-28-19S</td>
<td>4-#12</td>
<td>AN3057-16</td>
<td>15/16&quot;</td>
</tr>
<tr>
<td>8</td>
<td>700</td>
<td>MS3102A-28-2P</td>
<td>MS3102A-28-2S</td>
<td>MS3106A-28-2P</td>
<td>MS3106A-28-2S</td>
<td>2-#12</td>
<td>AN3057-16</td>
<td>15/16&quot;</td>
</tr>
</tbody>
</table>

**Note**

1) Current carrying capacity of contacts:
   - #16 - 22 amperes
   - #12 - 41 amperes

2) *Indicates carried in G. E. Stores

3) Male and female cable connectors shown will not mate with each other, they will mate with chassis connectors only. For mating cable connectors substitute MS3101A for one connector only. For example, MS3101A-12-5P will mate with MS3106A-12-5S.

4) "MS" designation was formerly "AN". For example; AN3102A-14S-9P is now MS3102A-14S-9P
# COAXIAL CONNECTORS

## TABLE III

<table>
<thead>
<tr>
<th>APPLICATION</th>
<th>CHASSIS CONN. (Female Recept.)</th>
<th>CABLE CONN. (Male plug)</th>
<th>TEE</th>
<th>RIGHT ANGLE ADAPTER (Male-Female)</th>
<th>UNION ADAPTER (Female-Female)</th>
<th>FOR USE WITH RG-58/U Cables</th>
</tr>
</thead>
<tbody>
<tr>
<td>UHF Series, low cost, general purpose, non weather proofed</td>
<td>Military # SO-239A #83-798</td>
<td>PL-259A, #49195</td>
<td>None</td>
<td>M-358, #49199 #83-11T</td>
<td>#83-1AP #83-117</td>
<td>8, 9, 10, 11 &amp; 12; 29, 29 &amp; 58 with UG-175/U 83-156 Adapter; 59, 62 &amp; 71 with UG-176/U 83-166 Adapter</td>
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<tr>
<td>EN Series, high voltage, weather proofed</td>
<td>Military # UG-560/U #82-804</td>
<td>UG-598/U #82-804</td>
<td>None</td>
<td>No Mill. No.</td>
<td>None</td>
<td>8, 9, 10, 11</td>
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<tr>
<td>NEV Series, high voltage (5000 V), miniature, quick disconnect, weatherproofed</td>
<td>Military # UG-931/U #82-804</td>
<td>IPC-27000</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>58, 59, 62, Belden #8301</td>
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</table>

* Indicates carried in General Electric Stores

## MICROPHONE AND AUDIO CONNECTORS

<table>
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<tr>
<th>APPLICATION</th>
<th>Typical Mfg. No.</th>
<th>CABLE CONN. (Male plug)</th>
<th>CABLE CONN. (Female plug)</th>
<th>CHASSIS CONN. (Male Recept.)</th>
<th>CHASSIS CONN. (Female Recept.)</th>
<th>CABLE CONN. (90° plug, female)</th>
<th>DIAMETER</th>
<th>CURRENT CARRYING CAPACITY</th>
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<tbody>
<tr>
<td>3-contact microphone connector. Snap-lock quick disconnect</td>
<td>Cannon # XLR-3-12SC</td>
<td>XLR-3-12SC</td>
<td>XLR-3-14</td>
<td>XLR-3-13</td>
<td>XLR-3-15</td>
<td>5/16&quot; Dia.</td>
<td>15 Amps</td>
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<tr>
<td>4-contact microphone connector. Snap-lock quick disconnect</td>
<td>Cannon # XLR-4-12SC</td>
<td>XLR-4-12SC</td>
<td>XLR-4-14</td>
<td>XLR-4-13</td>
<td>XLR-4-15</td>
<td>5/16&quot; Dia.</td>
<td>10 Amps</td>
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For sound powered phone connectors refer to Hartford Standard D-20-90, Sound Powered Telephone Receptacle.
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## COAXIAL CABLES

### TABLE IV

<table>
<thead>
<tr>
<th>RG/U Number</th>
<th>MANUFACTURERS #</th>
<th>IMPEDANCE (ohms)</th>
<th>NOMINAL VOLTAGE (volts RMS)</th>
<th>MAXIMUM CAPACITANCE (pF/foot)</th>
<th>CENTER CONDUCTOR</th>
<th>OUTSIDE DIAMETER at 1 MC (db/100 feet)</th>
<th>APPLICATION</th>
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<tr>
<td>RG-54A/U</td>
<td>AMPHENOL</td>
<td>58</td>
<td>3000</td>
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<td>Copperweld</td>
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<td>1.18</td>
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<td></td>
<td>BELDEN</td>
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<td></td>
<td>(8239)</td>
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<td>Good for radiation service; not for use out-of-doors. Fairly stiff</td>
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<td>RG-59/U</td>
<td>21-025</td>
<td>73</td>
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<td>RG-62/U</td>
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<td>(previously aquadag coated, RG-11/U low noise)</td>
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<td>25.0</td>
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### Note 1:
- All cables carried by G. E. Stores
- "Copperweld" is copper plated steel wire, its resistance is slightly higher than copper wire.
8. RELAY RACKS AND PANELS

Standard dimensions of cabinet racks and panels are shown in Figure II. They are published here for information. The following points should be noted:

a. The EIA\* or W. E. ** type drilling is the accepted standard.

b. Panel sizes A, B, C, E, G, J, L and M are carried by G. E. Stores. The open type slot is preferred.

c. Hanford Standard J-3-13, Instrument Rack Cabinet Installation shows mounting details for the cabinet racks.

d. All relay rack cabinet installations should be equipped with supports and chassis brackets as shown in Hanford Standard DI-J-3-13.

* Electronic Industries Association, formerly RETMA (Radio-Electronic-Television Manufacturers' Association) also formerly RTMA & RMA.

** Western Electric
a. Table V lists obsolete tubes that the manufacturer recommends not using for new equipment. Although these tubes are not, as yet, discontinued, their production has been curtailed. They are approaching obsolescence and should be avoided in new equipment design.

b. Table VI lists, for general information, premium or high reliability tubes and their prototypes. In some cases two industrial tubes exist for one prototype. The preferred tube is noted in this listing. Generally speaking all tubes with W, WA or WB following their prototype number are "ruggedized" or "military" tubes. Because their prototype number is obvious, they will not be listed.

c. Some premium tubes are not direct replacements for any prototypes. They are, however, recommended premium types and are listed here for general information:

(1) The 5686 and the 6094 are 9-pin miniature versions of the 6A05 (6005). The conservatively rated 5686 is preferred to the 6094 or the 6005.

(2) The 6203 and the 5993 are 9-pin miniature versions of the 6X4 (6202). It is the consensus of tube manufacturers that the small 7-pin socket of the 6X4 and 6202 should not be operated above 50 milliamps. All these tubes are rated at 70 ma output. The 6203 is preferred to the 5993, 6202 or the 6X4.

(3) The 5998 is preferred to the 6080 WA or the 6AS7 but its MU is 5.4 compared to 2 for the 6AS7 & 6080 WA. These tubes are interchangeable for voltage regulator applications but may not be for other applications.

(4) The 6336 has approximately twice the plate dissipation rating and approximately twice the plate current rating of the 6AS7.

(5) Other premium type tubes that are recommended are:

- 6AS6WA
- 6AU6WA
- 6AN5WA
- 5Y3-WGTA
- 5Y3-WGBT
- 5R4-WGB
- 5R4-WGA
TUBES NOT RECOMMENDED FOR NEW EQUIPMENT DESIGN

### TABLE V

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Information for table V taken from:

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* Recommended premium type
Note 1 - See Paragraph 9 c.
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* Recommended premium type

See paragraph 9c for information on underlined types
DG-500-AC

GUIDE FOR

MAINTENANCE OF ROOFING
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GUIDE FOR MAINTENANCE OF ROOFING

1. PURPOSE

The purpose of this guide is to recommend practices, materials and types of construction for repair of built-up roofing at Hanford. This guide is for use by maintenance personnel to obtain satisfactory roof repairs. It shall not be used as a substitute for construction specifications.

2. DEFINITIONS AND EXPLANATIONS OF TERMS
(See also illustration of terms, Fig. 1)

- **Base flashing** - Waterproofing system applied at the intersection of the roof deck and any vertical element of the structure.

- **Cant** - A triangular shape used to modify the 90 degree angles between the roof deck and any vertical element of the structure.

- **Counterflashing** - A covering, generally of metal, installed at roof penetrations and along vertical elements of a structure, extending down and over flashing or roofing felts as a final covering in the waterproofing system.

- **Fascia** - Metal or wood piece installed along roof edge generally for appearance but is also used as a nailer for gravel stops, roof edging or edge gutters.

- **Fishmouth** - Exposed lap edges that have curled, separated and lifted.

- **Roof flange** - Flat, horizontal section of metal edging or flashing installed in or on roofing.

- **Gravel stop** - A metal edging which acts as a retainer for final coat of bitumen and gravel at roof edge. It also provides a finished appearance to edge of roof.

- **Insulation stop** - A wood strip of the same thickness as the insulation, securely fastened to the roof deck where flashing and edging flanges are to be installed; also installed between joints of insulation on steep roofs.

- **Metal flashing** - Sheet metal or metal sleeves used at roof penetrations, valleys and hips as part of the waterproofing system.
**Parapet** - A building wall which extends above the roof.

**Pitch pocket** - A metal collar used where angle supports, guy wires, etc., are fastened through roofing. Collar is filled with roofing cement after being properly secured. In cases where roofing materials could eventually drip into the building, pocket is first caulked with oakum.

**Reglet** - A groove prepared or cast in a wall into which metal counterflashing is secured as finish protection for the base flashing system.

**Reinforcing fabric membrane** - Loosely woven cloth used to reinforce built-up roofing.

**Repointing** - Application of roofing cement to potential leak locations such as around metal flashings which are becoming loose.

**Trowelling** - Application of roofing cement or other compounds to surfaces, into cracks or at joints with the use of a metal trowel.

**Valley** - Area on a roof where two non-horizontal surfaces come together.

**Vapor barrier** - A barrier applied under roof insulation to protect it from moisture originating within the building.

**Wood nailers** - Wood strips installed in non-nailable decks and walls to furnish a base for securing the various elements of the roofing system.
To obtain the maximum service from a roof, periodic inspection and maintenance is essential. The first inspection should be made immediately after the installation of a new roof, or major roof restoration, as part of the acceptance procedure. Subsequent inspections should be made each fall and spring. As the result of the inspections, minor repairs can be made, and preventive maintenance can be scheduled. Successful roof maintenance is founded mainly on four factors: 1) timing, doing the job before the roofing is beyond repair; 2) proper preparation of roofing for the repair job; 3) care in making repairs and reinforcing weakened areas; and 4) using correct materials for the specific job at hand.

One problem in roof care that most persons do not appreciate is that roofs, especially those with insulated decks, are easily damaged. Concentrated loadings from any source on a graveled roof will force the gravel into the felt and create leaks that are difficult to find. Base flashing with exposed felt becomes brittle and is very susceptible to damage from work done near vertical walls or around curbed openings. There should be no unnecessary or careless traffic on roofs in general, and near vertical walls, curbs, and vents in particular. All storage of materials or equipment on roofs should be prohibited. Asphalt plank walkways should be installed in necessary traffic areas and their use should be insisted upon. All materials or equipment that must be transported across a roof should be done by hand or by the use of dollies provided with low-pressure pneumatic tires. When work is to be done on a roof, protection should be provided by planking carefully installed so that the planks do not damage the roof surface. Tools, equipment, loose pieces of metal or other foreign materials should not be allowed to lay on a roof over a period of time. They will gradually become embedded in the bitumen and eventually cause a leak. Persons who have access to roof areas should give roof care a high priority.

4. TYPES OF REPAIR

4.1 GENERAL

Whether a built-up roof should be patched, coated, or re-roofed depends on the age and condition of the roofing, the type of building and its use and the condition of the underlying decking.

4.2 PATCHING SMALL AREAS (See Section 6 of this guide)

Many leaks in built-up roofs are caused by failure of flashing. Flashings at parapet walls, at vents, and valleys are extremely important. In many cases patching or repointing the flashing cures a leak. Patching is an accepted economical practice in cases of minor damage or wear to an otherwise sound roof. However, if leaks start to occur in a roof that has been watertight for years, it is a reasonable warning that the whole roof may be ready to give up. Patching under these circumstances usually results in maintenance expense which is not justifiable.
4.3 PATCHING EXTENSIVE AREAS (See Section 7 and Section 11 of this guide)

It is often possible to save a large area of satisfactory roofing containing an area which has been badly damaged and is too large for successful minor patching or repair. In these cases it becomes necessary to remove the entire area of damaged roofing and replace it with built-up roofing similar to the original roofing system.

4.4 COATING FOR PROTECTION (See Section 8 of this guide)

The life of a smooth surfaced or gravel surfaced built-up asphalt roof can be extended for several years by the application of a coating of a clay-type asphalt emulsion. However, this treatment is effective only if the coating is applied while the original built-up roof is in good, serviceable condition. This treatment can be repeated after several years, depending on the amount of asphalt emulsion applied, thus further extending the roof's life.

4.5 COATING WITH REINFORCING FABRIC (See Section 9 of this guide)

When smooth or gravel surfaced asphalt roofing has deteriorated to a point where patching or coating for protection is not applicable, the roof can be coated using reinforcing fabric membrane and clay-type asphalt emulsion. The fabric adds tensile strength to the coating system not otherwise obtained. The reinforcing system has the advantage of being light in weight and lower in cost than re-roofing or re-covering. It can be applied in hard-to-reach areas or where the use of hot materials would be difficult.

4.6 RE-COVERING (See Section 10 of this guide)

If the original roofing is securely attached to the deck and not badly deteriorated, and the underlying insulation (if any), and roof decking are in good condition, it may be advisable to repair the existing roof and re-cover with a new built-up assembly. This may also be done where weather conditions or other factors prohibit a complete roof removal.

4.7 RE-ROOFING (See Section 11 of this guide)

If the roof has been re-covered one or more times, or if the original roof is badly deteriorated, or if the original roofing is not securely attached to the deck, or if the underlying insulation has become water-soaked or otherwise deteriorated, or if the roof decking has deteriorated or become damaged, all old roofing and flashing should be completely removed, the deck reconditioned to conform with the requirements for new construction, and a new roof applied.

5. MATERIALS

5.1 GENERAL

Materials for use in roof repair should be as follows:
ROOF INSULATION

Roof insulation should match type in existing system being repaired. Fiberboard insulation should be an asphalt treated and coated, rigid type insulation intended for use with built-up bitumen-bonded roofs such as: Flintkote Co., Flintkote "Canec"; Johns-Manville Standard Coated "Roofinsul"; or Celotex Corp. "Prescale"; or similar product meeting the American Society for Testing Materials (ASTM) Designation: C208, Structural Insulating Board Made from Vegetable Fibers, Class C, with asphalt treatment and coating and the additional specification that the composition and surface of the material shall be such that a thorough bond is effected to asphalt or pitch over 100% of the area to which it is applied, without permitting bitumen penetration that would reduce the bond to the material or insulating efficiency of the material.

5.3 ROSIN-SIZED PAPER

Rosin-sized building paper weighing not less than 5 pounds per 100 square feet.

5.4 COAL-TAR PITCH

Coal-tar pitch shall have a softening point within the range of 140°F to 150°F; Koppers, "Old Style Pitch"; or similar product meeting Federal Specification R-P-381, Type I or ASTM Designation D450, Type A.

5.5 ASPHALT

Low melt asphalt for roof slopes 0" to ½" per foot shall have a softening point between 140°F and 145°F, such as: Flintkote Co., "Certified Level-Dek"; Johns-Manville, "Aquadam"; Fry, "Ded-Level Bitumen"; or similar product conforming to the Corps of Engineers Interim Guide Specification CE 220.01, Type A or B.

High melt asphalt for roof slopes over ½" per foot shall have a softening point between 165°F to 190°F, such as: Flintkote Co., "Certified HMP Asphalt"; Johns-Manville, "Standard 190 Asphalt"; Fry, "Roofing Asphalt"; or similar material conforming to Federal Specification SS-S-666, Type II, Grade 2 or ASTM Designation D312, Type (c).

5.6 COAL-TAR SATURATED ROOFING FELT

Coal-tar-saturated rag felt weighing not less than 13 pounds per 100 square feet (commonly referred to as "15-pound felt"); Koppers Co., "Koppers Tarred Felt"; or similar felt conforming to Federal Specification HH-F-201 or ASTM Designation: D227.

5.7 ASPHALT-SATURATED ROOFING FELT

Asphalt-saturated rag felt weighing not less than 13 pounds per 100 square feet (commonly referred to as "15-pound felt"); Flintkote Co. "No. 15 Asphalt Felt"; Johns-Manville, "No. 15 Asphalt-Saturated Felt"; Fry, 15-lb "Asphalt-Saturated Felt"; or similar felt conforming to Federal Specification HH-F-191 or ASTM Designation: D226.
5.8 SPECIAL ROOFING SHEETS

Asphalt-saturated and coated sheets weighing not less than 50 pounds per 100 square feet: Flintkote, "Ironclad Base Sheet"; Paboo "53 pound Ilmenite Base Sheet"; Fry "55 pound Super Smooth Roll Roofing" or similar material conforming to Federal Specification SS-R-50la, Class B or ASTM Designation: D224, 55 lb Grade.

5.9 GLASS FABRIC

Woven glass fabric for use in reinforcing patches and membrane waterproofing on built-up roofs: Flintkote, "Yellow Jacket Glass Cloth"; Johns-Manville, "Duramesh Type 931 Reinforcing Fabric"; Owens-Corning, "Fiberglas Corotop"; or similar material conforming to Federal Specification HH-C-00466.

5.10 MINERAL SURFACED ROOFING

Mineral surfaced roofing for use in base flashings; asphalt-saturated rag felt surfaced with mineral granules and weighing at least 83 pounds per 100 square feet (referred to as "90 pound roofing") with 2 or 1/2 inch base edge lap: Fry, "90 lb Slate Roll Roofing"; Flintkote, "No. 95 Mineral Surfaced Cap Sheet"; or similar material conforming to Federal Specification SS-R-521, Type I or ASTM Designation D249.

5.11 ASPHALT EMULSION

Asphalt emulsion shall be a stable, clay-type emulsion designed and manufactured for protective coating of built-up and metal roofing: Flintkote, "Hydralt C-13-C", for built-up roofing, C-13-HPC for metal roofs; or a similar material conforming to Military Specification MIL-R-3472, except that resistance to re-emulsification shall be determined as follows:

A 1/8 inch thick film of emulsion shall be applied to a minimum 2-inch by 2-inch area of a clean glass panel. The panel shall be dried in an oven at 110 F for 24 hours. To meet these specifications the emulsion film shall not disintegrate or re-emulsify when the test panel is submerged in a vertical position in distilled water at room temperature for 24 hours. The emulsion shall be considered not re-emulsifiable if the film maintains its adhesion to the glass panel without dropping of its own weight after 24 hours immersion and, if by slight rubbing with the fingers, the emulsion film does not disintegrate and become suspended in the distilled water. Slight surface stain or rusting of the emulsion film will not be considered re-emulsification.

5.12 ROOFING CEMENT

13 CAMTS

Wood or rigid fiber board, triangular in cross section, 3½" minimum both horizontal and vertical dimension. On wood cants, 90 degree corner mitered. Douglas Fir Wood Cants; Flintkote, "Flintkote Canec Cant Strip"; Celotex Corporation, "Celotex Cant Strip" or similar equal product.

5.14 NAILS, SCREWS AND DISCS

Roofing nails are 10 gage, one inch long, hot-dipped galvanized, with heads not less than ¾ inch in diameter. Nails for attaching metal flashing are 10 gage, 1½ inches long, hot-dipped galvanized. Screws for attaching metal flashing are No. 8, one inch long, zinc or cadmium plated, stove head sheet metal screws. Tin discs for use with roofing nails shall have a minimum diameter of one inch.

5.15 ROOFING GRAVEL

Roofing gravel shall consist of hard, dry, round stones free from sand, clay, dust or any other foreign matter. Crushed stone or crushed gravel shall not be used. Gravel shall have a size range of 5/8 inch minus to 1 inch plus. Gravel removed from existing roofs shall not be reused.

5.16 ASPHALT PLANK

Asphalt plank for walkways shall be one inch thick by eight inches wide, plain asphalt plank, Philip Carey, Mfg. Co. "Elastite Asphalt Plank" or similar product conforming to ASTM Designation: D517.

5.17 SHEET METAL FOR FLASHING AND GRAVEL STOPS

Galvanized sheet metal shall conform to Federal Specification QQ-S-775a, Type I, Class d or ASTM Designation: A361. Copper sheet metal shall conform to Federal Specification QQ-C-576a, light cold rolled temper.

5.18 ZINC DUST-ZINC OXIDE PROTECTIVE COATING FOR METAL

DuPont-Eng-1007 "No. 765 Dulux Galvanized Metal Primer"; Sherwin-Williams Co., "Galvanized Iron Primer", or similar product meeting Federal Specification TT-P-641b, Type II.

5.19 PRIMER

A solution of soft asphalt which prepares the surface of steel and concrete for a firm bond with asphalt coatings; Flintkote, "No. 620 Industrial Primer"; Johns-Manville, "Concrete Primer"; Fry, "Asphalt Concrete Primer No. C-31"; or similar material conforming to Federal Specification SS-A-701, or ASTM Designation: D41.

5.20 LUMBER FOR INSULATION STOPS AND NAILERS

Lumber for insulation stops and nailers shall be Douglas fir, "Standard" Grade.
5.21 PLASTIC SHEET VAPOR BARRIER & ADHESIVE FOR STEEL ROOF DECKS

Plastic sheet vapor barrier for steel decks shall consist of a vinyl plastic sheet of 0.004 inches minimum thickness cemented to roof deck. Plastic sheet and adhesive for applying sheet to the deck and for applying insulation to the sheet shall be specifically manufactured for use as vapor barrier materials, Lexsoo, Inc. "Koroseal Vapor Barrier & Adhesive R907T" or Philip Carey Inc., "Fire-chex" vapor barrier and "Adhesive No. 400" or similar product listed and approved for use in built-up roofing by Underwriters Laboratory Inc., or Factory Mutual Laboratories.

5.22 STORAGE, HANDLING AND PREPARATION OF MATERIALS

a. All materials, including gravel, shall be kept clean and dry and shall be protected from the weather during storage and application.

b. Rolls of felt shall be stored in an upright position and shall be protected from damage during storage and application.

c. 50 pound felt shall be cut to required size, not more than 18 ft lengths, and shall be allowed to flatten in plies before using.

d. Glass fabric shall be handled carefully to prevent kinking, or creasing as this will cause it to break at the crease.

e. Extreme care shall be used to control the temperature of asphalt and pitch during heating. If a batch is overheated, it shall be discarded. A spear type thermometer shall be provided and it shall be used by the kettleman to maintain asphalt and pitch temperatures within the specified limits. The melting kettle shall not be placed on the roof. (See Section 12 for other safety requirements.)

f. Asphalt shall not be heated above 425 F for high melt asphalt or 400 F for low melt asphalt. Temperature of asphalt when applied shall not be less than 350 F for high melt asphalt or 325 F for low melt asphalt.

g. Pitch shall not be heated above 375 F. Temperature of pitch when applied shall not be less than 300 F.

h. Asphalt, pitch, and asphalt emulsion shall not be adulterated in any way.

i. Asphalt emulsion shall not be allowed to freeze. It shall not be used during rainstorms because of the problem of dilution from the rain.

j. Leaky containers shall not be used for handling asphalt, asphalt emulsion, pitch or roofing cement. If such materials are spilled or spattered on permanently exposed surfaces of structures the material shall be completely removed.

k. Material handling dollies and other wheeled equipment used on new or existing roofs shall be equipped with low pressure pneumatic tires.
1. Materials and/or equipment shall not be used on, stored on, or transported over existing or new roofs unless protection is provided to prevent damaging or overloading the roof deck, built-up roofing components and the structural system.

5.23 COMPATIBILITY OF COAL-TAR AND ASPHALT MATERIALS

Coal-tar pitch and asphalt are not compatible and no attempt should be made to inter-mix roofing systems. Asphalt-saturated felt must be used only with asphalt, and coal-tar-saturated felt only with coal-tar pitch. To re-cover one roofing system with another, the covered system must be isolated. (See Section 10.2a.)

There is one exception: asphalt base roofing cement (Fed. Spec. SS-C-153, Type I) can be used with either asphalt or coal-tar pitch systems.

To determine whether the existing roofing is coal-tar or asphalt, remove a small sample of the roofing material and heat it with a flame and observe the odor. Compare this odor with a known sample.

6. PATCHING SMALL AREAS (See Section 4.2 of this guide)

6.1 MINOR DAMAGE

a. Smooth Surfaced Roof

(1) Small areas that are damaged and locations that are wearing excessively along edges and base flashing can be patched with woven glass fabric and clay-type asphalt emulsion.

(2) Clean areas to be repaired. Trim any hard, curled edges or fishmouths to provide a smooth surface. Apply a 1/16" thick embedding coat of asphalt emulsion extending 4 inches beyond repair area. Lay in glass fabric cut to size of emulsion coat, and brush out wrinkle-free. After embedding coat is set and fabric is firmly embedded, apply a 1/8" finish coat of asphalt emulsion so that fabric is not visible.

b. Gravel Surfaced Roof

(1) Coal-Tar Pitch Roof

Small areas that are damaged or excessively worn can be patched with 2 layers of 15-pound coal-tar-saturated roofing felt and coal-tar pitch.

Remove gravel in area to be patched and for 8 inches surrounding area. Trim any hard, curled edges or fishmouths to provide a smooth surface. Clean area thoroughly of all dust and debris. Area must be dry when repairs are made.

Apply one layer of felt, laid in a 1/8" coating of roofing cement and cut to extend 4 inches beyond location on all sides. Mop felt and surrounding area for 4 inches thoroughly with hot coal-tar pitch at the rate of 30 pounds per 100 square feet. Embed second layer of felt, cut 4 inches larger in all directions, in the hot pitch. Broom immediately to insure good adhesion.
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Flood patch area and slightly beyond with hot pitch at the rate of 75 pounds per 100 square feet. Embed gravel in the hot pitch, at the rate of not less than 400 pounds per 100 square feet. Spread gravel evenly to prevent piles or humps which could act as a water dam.

(2) Asphalt Roof

Small areas that are damaged or excessively worn can be patched and reinforced with 1 layer of 50-pound roofing felt or 2 layers of 15-pound asphalt roofing felt, and hot asphalt. Proceed in the same manner as for a coal-tar pitch patch, Section 6.1, b, except when using 50-pound felt apply only one layer cut 8 inches larger than the damaged area; also in either case apply hot asphalt instead of coal-tar pitch.

6.2 LARGE BREAKS

a. Smooth Surfaced Roof

(1) Where most of the roof is still in good watertight condition, but larger splits and breaks need to be repaired, they may be patched by the use of 50-pound felt, clay-type asphalt emulsion, and woven glass fabric.

(2) Trim any hard, curled edges or fishmouths to provide a smooth surface. Clean area of all dirt and debris. Apply a layer of 50-pound felt over the repair area laid in roofing cement. Width of felt strips should be sufficient to extend 8 inches beyond each side of the break.

Over the 50 pound felt, apply a 1/16" coating of asphalt emulsion to embed a strip of woven glass fabric, extending 4 inches beyond each side of the felt. After the asphalt emulsion has "set" apply another coat of asphalt emulsion 1/8" thick so that the fabric is not visible. The felt acts as a slip sheet and greatly reduces probability of the split being transmitted through to the top membrane.

b. Gravel Surfaced Roof

Large splits and breaks can be patched as described in Section 6.1, b, Item 1 or Item 2.

6.3 INSULATION

If insulation is wet, damaged, or otherwise deteriorated it should be replaced.

a. Surface Preparation

(1) Remove insulation and vapor barrier down to the roof deck. Insulation should be removed in full sections where practicable so that replaced sections will not require cutting. If possible, leave 6-8 inches of the vapor barrier system along edges of remaining insulation so that it can be folded back and cemented to the top surface of the remaining insulation.
(2) Clean and repair deck as described in Section 11.1, a & b, for wood decks or Section 11.1, a & c for concrete decks. If roof deck is steel, remove rust and scale by wire brushing. If wood insulation stops are involved in the repair area, remove and replace damaged or rotted stops. Fasten all stops to the deck with stove head sheet metal screws or oval head bolts spaced not more than 24 inches on centers.

b. Replacing of Vapor Barrier and Insulation

After the deck surface has been cleaned and repaired, the new vapor barrier and insulation are applied as described in the Hanford Standard Specifications for Applying Insulation, HWS-6141-S for wood decks, HWS-6142-S for concrete decks, and HWS-6143-S for steel decks. (See Section 11.2.)

6.4 BLISTERS - WRINKLES

Where roofing has pulled away from the deck or underlying felts and has formed blisters and wrinkles, make an X cut in the blister or wrinkle so that the roofing can lay flat. Trim edges of the cut area so that there is no overlapping when roofing is flattened down. Trowel a 1/8" thick coating of roofing cement under cut area. Nail cut edges if it is a wood deck and patch as described in Section 6.2, a, if it is a smooth surfaced roof. If it is a gravel surfaced roof, patch as described in Section 6.1, b, Item 1 or 2.

6.5 VALLEYS

a. Smooth Surfaced Roof

Where reinforcing appears desirable, clean area first and hose down to a dust-free condition. Allow to dry and apply an embedding coat of clay-type asphalt emulsion at a minimum rate of 2 gallons per 100 square feet. Embed woven glass fabric over area to be patched. Brush fabric in so as to follow contour of roof and be free of wrinkles. After the embedding coat has "set" and the fabric is firmly adhered, apply a second coat of asphalt emulsion at a minimum rate of 6 gallons per 100 square feet. Run fabric up inclines at least 12 inches and up to flashing line at vertical walls.

b. Gravel Surfaced Roof

Valleys can be repaired or reinforced as described for Minor Damage, Section 6.1, b, Item 1 or 2. Run felt up inclines at least 12 inches and up to flashing line at vertical walls.

6.6 FLASHING

a. Base Flashing

(1) To repair base flashings which are pulled away from the wall at upper edge, force roofing cement behind the felt and then scal the edge with a 6-inch wide strip of woven glass fabric and clay-type asphalt emulsion as detailed in Section 9.1.
(2) Repair minor breaks in base flashings by cementing a layer of 50 pound felt over damaged area with roofing cement. Apply woven glass fabric and asphalt emulsion over the base sheet as outlined in Section 9.1.

(3) To reinforce base flashing along its entire length first broom clean the existing surface free of dirt and dust. Apply a 1/16 inch thick coat of asphalt emulsion from flashing line under metal counterflashing down into valley and out onto roof at least 24 inches. Embed woven glass fabric brushed out wrinkle free. When first coat is set up, apply a second coat and a second layer of woven glass fabric as above. Apply a finish coat of asphalt emulsion at the rate of 5 gallons per 100 square feet.

(4) If base flashing has deteriorated so that patching or reinforcing is not practicable, remove all base flashing material down to the roofing and bare wall. The actual roofing plies should extend up the wall to a point just above the cant. Do not remove any of these plies. Clean the area to be repaired of all dirt, dust and debris.

(a) Base flashing consisting of 4 plies of 15-pound rag felt (coal-tar felt for repair of coal-tar roofing and asphalt felt for repair of asphalt roofing) and 1 ply of 90-pound mineral surfaced roofing should be applied over all cants. All new base flashing plies must be trimmed evenly at a height such that the metal counterflashing overlaps the base flashing the full height of the counterflashing.

(b) The first ply of flashing felt extends onto the roof 3 inches beyond toe of cant; the second ply extends 5 inches beyond toe of cant; third ply extends 7 inches beyond toe of cant; fourth ply extends 9 inches beyond toe of cant. Mineral surfaced roofing extends 12 inches beyond toe of cant. Each ply and the mineral surfaced roofing is set in a 1/8" thick coating of plastic roofing cement. Felt shall be applied in strips not over 10 feet long with staggered 3-inch end laps sealed with roofing cement. All plies shall be carefully pressed into cement to eliminate buckles and blisters. Mineral surfaced roofing is to be cut in strips across the roll. Selvage shall be troweled with roofing cement and overlapped by the next piece. Water shall flow over, not against, lap edges. Flashing is nailed to wood nailers, curbs, or walls (as applicable) through all plies along top edge using roofing nails and tin discs on 12-inch centers.

(c) Where new flashing joins existing flashing, a cant of roofing cement, minimum of 4 inches wide, must be trowelled along edge of existing flashing to effect a smooth transition of the new flashing onto the existing flashing. Plies of new flashing shall extend over existing flashing and be cemented with roofing cement as follows:
b. Metal Flashing, Flanges, Gravel Stops and Edging

(1) All reusable galvanized metal work in the area of repair should be carefully removed, wire brushed, and coated with two coats of a zinc dust-zinc oxide primer. If metal is copper, no protective coating is required. Badly deteriorated metal should be replaced.

(2) Metal flashings, gravel stops, and edging are reinstalled after all roofing repairs are made.

(3) All roof flanges are set in a 1/8" thick trowelling of roofing cement. Roof flanges are nailed to the wood deck (or wood nailers on concrete or insulated decks) on 3-inch centers, 3/4 inches from back edge of roof flange. In addition, gravel stop roof flanges are secured to nailers with stove head sheet metal screws on maximum 24-inch centers. Gravel stop or edging fascia is secured to building siding or structure with stove head sheet metal screws on maximum 36-inch centers. Nail and screw heads in roof flanges are troweled with roofing cement.

(4) Joints in gravel stops, edging and counterflashing over base flashing are lapped 4 inches. Laps in gravel stops are sealed over the entire roof flange and gravel stop bead area with roofing cement. All excess roofing cement must be carefully and completely removed from permanently exposed metal surfaces.

(5) Roof flanges are sealed to roof with two plies of the plying materials used in the built-up roof, or patched area involved, mopped solidly to roof and flanges with hot asphalt, coal-tar pitch, or asphalt emulsion whichever was used for repair job. The first ply covers approximately half of the flange and extends onto roof 3 inches beyond edge of flange. The second ply covers the full width of roof flange and extends onto roof 6 inches beyond edge of flange. At roof penetrations a one-inch cant of roofing cement is applied at the intersection of the penetration flashing and the sealing plies.

(6) Pitch pockets, when used, are completely filled with roofing cement. If the pitch pocket extends through the deck so that pitch, or asphalt could eventually drip into the building, it should first be caulked with oakum.

6.7 ASPHALT PLANK WALKWAYS

Asphalt plank walkways, when required, are installed on top of the built-up roofing plies before the top flood coat is poured. They are set in hot bitumen leaving approximately 2 inches clear between adjacent pieces of plank. The final roofing surface is applied between planks at the same time and in the same method and amount as the rest of the roof.
surfaces of plank do not receive emulsion, pitch, asphalt or gravel.

7. PATCHING EXTENSIVE AREAS (See Section 4.3 of this guide)

7.1 GENERAL

a. Before patching extended areas of built-up roofing it is necessary to determine the original roofing system. To do this it may be necessary to review the original specifications and/or drawings for the building.

b. The area concerned should be replaced in accordance with the original specifications for that roof and as described in Section 11, Re-roofing.

c. In the absence of the original specifications, it is recommended that the Hanford Standard Specifications for Built-Up Roofing be used, with particular attention given to the treatment of the edges of the existing roofing where they join the new roofing. (See Section 11.2 for list of Hanford Standard Specifications for Built-Up Roofing.)

8. COATING FOR PROTECTION (See Section 4.4 of this guide)

8.1 SMOOTH SURFACED ROOF

a. Remove all dirt and debris. Clean valleys, gutters, drains and cutlets. Inspect all areas, flashings and metal work to determine extent of necessary repairs. Hose off existing roofing with water to remove all remaining dust and dirt, etc.

b. Repair and reinforce weakened areas in accordance with procedures outlined in Section 6. Clean and repaint metal flashing as described in Section 6.6, b.

c. Over the clean, dry, watertight roof, apply by brush or spray a coating of asphalt emulsion at the rate of 3 gallons per 100 square feet. When first coat has set up, apply a second coat at the same rate. Apply both coats to a uniform thickness, brushing out each coat with a soft fibered broom to achieve a smooth finish. Apply coatings up over flashing and on inside of parapet walls up to the top of flashing.

8.2 GRAVEL SURFACED ASPHALT ROOF

a. Remove all loose gravel with a heavy, stiff broom. Remove all dirt and debris. Clean out valleys, gutters, drains and outlets. Hose off roof with a strong jet of water to remove dust settled in the gravel. Inspect all areas, flashing and metal work to determine amount of repairs needed.

b. Repair roof and flashings as described in Section 6.

c. Apply asphalt emulsion as detailed for smooth surfaced roofs, Section 8.1, c.
COATINGS WITH RETROFITTING FABRIC (See Section 4.5 of this guide)

9.1 SMOOTH SURFACED ROOFS

a. Clean and inspect roof as described in Section 8.1, a.

b. Repair weakened areas and metal flashings as described in Sections 6.2, 6.4 and 6.6, b.

c. After repairs are completed, hose down the roof with a strong jet of water to remove all dirt and dust. When dry, apply 2 gallons of asphalt emulsion per 100 square feet and embed a layer of glass fabric. Lap ends 4 inches and sides 2 inches. It is important that the fabric be broomed into the emulsion with a wide, soft fibered broom so that it is free of wrinkles and follows the contours of the roofing without bridging in low spots. When the embedding coat is "set" apply a coat of emulsion over the fabric at the rate of not less than 5 gallons per 100 square feet.

9.2 GRAVEL SURFACED ASPHALT ROOF

a. Spud off all gravel and top surfacing of asphalt used to bond the gravel, to achieve a smooth felt surface. Care should be taken not to damage existing felts.

b. Repair weakened areas and metal flashings as described in Sections 6.2, 6.4 and 6.6, b. In valleys, at base flashing, and at roof penetrations for vents, etc., apply an extra layer of fabric embedded in and covered with asphalt emulsion as detailed in Section 9.1, c.

c. Apply asphalt emulsion and glass fabric in the same manner as for a smooth surfaced roof, Section 9.1, except that the final coat of emulsion is applied over the fabric at the rate of not less than 6 gallons per 100 square feet.

9.3 METAL ROOFS (corrugated)

a. A complete overlay of fabric on corrugated metal roofs is not normally recommended. Usually, sealing the seams and coating the entire surface stops pinhole leaks in the metal and leaks at the metal laps and retards corrosion.

b. Remove all dirt, debris, grease or oil and sweep clean. Wire brush the surface to remove scale and rust if they are present. Straighten deformed sheets, remove all loose nails or screws, and fasten loose laps with self-tapping sheet metal screws.

c. Along the vertical laps, apply a coating of asphalt emulsion at the rate of 5 gallons per 100 linear feet in a strip 8-inch wide. Into this coating, embed a 6" wide strip of glass fabric. With a soft, wet brush, mould the fabric strips from flush with the lower horizontal edge of the metal sheet to up under the overlapping sheet at least 2". Seam sealing of horizontal laps is not recommended.
d. Upon completion of the seam sealing, apply a coating of asphalt emulsion over the entire roof at a minimum rate of \(3\frac{1}{2}\) gallons per 100 square feet of roof area. Spray application is preferable. If applied by brush, maintain uniform film thickness in valleys and ridges of corrugations.

10. RE-COVERING (See Section 4.6 of this guide)

10.1 GENERAL

The methods of preparation and application in re-covering existing roofing depend upon the type of deck and the nature of the existing roof surface. The roofing system to be used (number of plies and bonding material) will depend upon the ability of the roof deck and building structure to sustain the additional weight of the added roofing materials (200-650 pounds per 100 square feet).

10.2 SURFACE PREPARATION

a. Coal-tar pitch is incompatible with asphalt. If it is planned to re-cover an existing coal-tar pitch built-up roof with an asphalt built-up roof, or vice-versa, special precautions are necessary. After removing all loose gravel and debris, the existing roof must be covered with \(\frac{1}{2}\) inch or thicker roof insulation laid in the same kind of bitumen used on the existing roof. Subsequently, the prepared surface should be covered with the desired type of built-up roof. New roofing should never be solidly mopped to old roofing, because this tends to transmit old cracks through to the new roofing. Unless these precautions are observed an unsatisfactory roof may result.

b. Old gravel roofs must be spudded free of all gravel until a smooth surface is obtained. Particular care must be taken that no gravel remains embedded in the surface. If it is impossible to remove all embedded gravel, apply one layer of \(\frac{1}{2}\) inch or thicker roof insulation embedded in a 35 pound per 100 square feet mopping of hot asphalt or pitch as appropriate and treat as a new insulated deck when recovering.

c. All blisters, buckles, wrinkles, fishmouths and otherwise deteriorated or wet roofing must be either cut free and the affected area patched to a smooth surface, or repaired as described in Section 6.

d. Wet roofing, if in otherwise good condition may be partially freed and laid back until the area is completely dry. When dry, roofing should be nailed in place if on a wood deck or spot mopped in place if over a non-nailable deck. The edges of the section must then be repaired as described in Section 6.2 and 6.4.

e. On insulated decks the insulation should be inspected. If parts of the insulation are soft, spongy, watersoaked or otherwise deteriorated, these parts must be replaced with new material of like thickness. Repair of this nature is described in Section 6.3 a and b.
f. All old base flashing at walls and curbs must be repaired to a water-tight condition as described under Section 6.6, a and b. All reusable metal flashing, counterflashing, gravel stops, etc., shall be removed. Badly deteriorated metal should be replaced. See Section 6.6, b.

g. Rotted or otherwise deteriorated cants shall be replaced. Cants left out in original construction should be installed unless there are obvious reasons for their omission.

h. All cracks in the old felts should be repaired as described in Section 6.1, a or b.

i. When re-covering it is often wise economy to include roof insulation. It can be laid over the old felts after thorough cleaning and preparation of existing roofing. Laying insulation in this case is similar to installation of insulation to a vapor seal and is described in HWS-6142-S, Standard Specification for Applying Insulation to Concrete Decks. It offers a smooth surface for the built-up re-covering and also helps remove the possibility of old cracks being transmitted to the new roofing by absorbing vibration and deck shifting.

10.3 APPLICATION

Re-covering of roof with new built-up roofing should be done in accordance with one of the Hanford Standard Specifications HWS-6144-S through HWS-6149-S. (See Section 11.2 for listing of Hanford Standard Specifications for Built-Up Roofing.)

11. RE-ROOFING (See Section 4.3 and 4.7 of this guide)

11.1 SURFACE PREPARATION

a. All old roofing must be removed right down to the decking. The deck must be carefully inspected for defects and thoroughly cleaned of dirt, dust and other debris and washed, if necessary, with a jet of water to leave a clean, dust-free area for the new roof.

b. If the deck is of wood, all rotten or cupped boards must be replaced, loose boards nailed securely and protruding nails removed. Knot holes and voids $\frac{1}{2}$ inch or over in least dimension should be covered with minimum 26 gage galvanized sheet metal securely nailed to the deck. Deck must be smooth, free of depressions or projections.

c. If the deck is concrete, disintegrated or damaged concrete should be repaired and cracks filled with concrete patching materials or roofing cement.

(1) Cracks of $\frac{1}{2}$ inch or over in least dimension, may be filled with a mortar consisting of one part portland cement and three parts sand (by volume) with sufficient water added to give the proper consistency so that the mortar can be packed into the crack until a smooth surface with the crack edges is obtained.
(2) Cracks smaller than $\frac{1}{2}$ inch in least dimension may be trowelled with roofing cement, working the cement into the crack until a smooth surface with the crack edges is obtained.

(3) Cracks of a serious nature which affect or appear to affect the structural strength of the concrete deck should be referred to an engineer for required repairs.

d. All old flashing must be cut away and stripped from all walls, curbs, etc. The walls, curbs, etc., must then be cleaned, repaired, or otherwise conditioned to conform with the requirements for new construction.

e. Damaged or deteriorated cants shall be replaced and new cants should be installed wherever originally omitted unless obvious reasons, or original drawings, indicate necessity for omission.

f. All metal work must be removed. These should be cleaned and reconditioned if in suitable condition. Badly deteriorated metal should be replaced. See Section 6.6, b.

11.2 APPLICATION

The cleaned and reconditioned deck should be roofed as specified for a new deck of similar construction, as selected from Hanford Standard Specifications for Roofing, HWS-6141 through HWS-6149-S. These standard specifications for built-up roofing are excellent guides for roofing construction and are in the Architect-Civil Standards book under the section "ROOFING". Single copies of these Standard Specifications may be obtained from Reproduction. They are:

- DI-6141-6149-S, Instructions for Use of HWS-6141 through HWS-6149-S
- HWS-6141-S, Applying Insulation to Wood Roof Decks
- HWS-6142-S, Applying Insulation to Concrete Roof Decks
- HWS-6143-S, Applying Insulation to Steel Roof Decks
- HWS-6144-S, Built-Up Gravel Surfaced Coal-Tar Roofs on Wood Decks
- HWS-6145-S, Built-Up Gravel Surfaced Coal-Tar Roofs on Concrete Decks
- HWS-6146-S, Built-Up Gravel Surfaced Coal-Tar Roofs on Insulated Decks
- HWS-6147-S, Built-Up Smooth and Gravel Surfaced Asphalt Roofs on Wood Decks
- HWS-6148-S, Built-Up Smooth and Gravel Surfaced Asphalt Roofs on Concrete Decks
- HWS-6149-S, Built-Up Smooth and Gravel Surfaced Asphalt Roofs on Insulated Decks

12. SAFETY, HEALTH & FIRE CONSIDERATIONS

There are numerous safety, health and fire prevention regulations which must be observed while handling roofing materials and equipment, and during the application of hot roofing bitumens. For specific information see the State of Washington, Safety Standards for Construction Work and contact the Area Safety, Health and Fire Prevention Specialists.
DG-501-AC

GUIDE FOR

REPAIR OF CONCRETE BLOCK WALLS
1. PURPOSE

The purpose of this guide is to recommend materials and procedures for repair and maintenance of concrete block building walls at Hanford. This guide is for the use of maintenance personnel to obtain satisfactory block wall repairs and should not be used as a substitute for construction specifications.

This guide is not intended as a substitute for engineering inspection and analysis where it is needed. Where there is reason to believe that the structural integrity of a building or wall has been impaired, a structural engineer should be consulted before attempting repairs.

2. TYPES OF REPAIRS

The most common conditions requiring repairs to concrete block walls are:

a. Cracks and open joints
b. Penetrations
c. Loose and broken blocks
d. Leaking exterior walls exposed to weather.

3. REPAIR OF CRACKS AND JOINTS ABOVE GRADE

3.1 OPEN JOINTS, HOLES AND LOOSE BLOCKS

a. Mortar for filling open joints, resetting loose blocks or patching holes in individual blocks should be a non-metallic, non-shrinking, gray colored, waterproof joint mortar. "Dryjoint Pointing Mortar" as produced by Standard Dry Wall Products, Inc., is an example of a commercially available material which is suitable for these types of repairs where the areas involved are normally dry. Such material is preferable because it is non-staining and does not shrink while drying, as does portland cement grout.

b. Open joints which are confined to a small area, such as those caused by deterioration of the original mortar or as a result of physical damage, can best be repaired by rodding and tuck-pointing with pointing mortar.
c. For resetting loose blocks, the original mortar may be chiseled away, the joint cleaned of loose granular material by blowing out with compressed air, and fresh pointing mortar placed by rodding and tuck pointing. If the block is completely loose it should be removed, old mortar disposed of and the block repositioned with wooden wedges. Fresh mortar should be placed as stated above and the wedges removed as placement proceeds. Wedges should be removed when the mortar will support the blocks without settlement. The joint surfaces should be dry when the mortar is placed.

3.2 CRACKS AND JOINTS WITH EXPANSION MOVEMENT

a. Where cracks and open joints above grade are subject to expansion and contraction, the material used to fill the crack should be a light gray, polysulphide rubber conforming to the requirements of ASA A116.1-1960, Class B (Non-sagging). The material has good bond strength to clean concrete, good weather resistance and a high degree of elasticity through a wide range of temperatures. A. C. Horn Co. "Hornflex LP32" Sealant and "Hornflex" Primer is an example of a commercially available system which meets the requirements stated above.

b. Open joints which are subject to expansion and contraction occur most often where the block wall is a non-load-bearing panel in steel or reinforced concrete column and girder construction. For a good repair with polysulfide rubber, porous surfaces such as concrete block should be primed. Primer used should be a product of the same manufacturer as the sealant. Both primer and sealant are 2-component compounds consisting of a polysulfide base compound and a catalyst. Mixing of the components must be in strict conformance with the manufacturer’s instructions on the package. The primer may be applied with a knife or a stiff-bristled brush similar to a tooth brush. The sealant may be applied with a knife or caulking gun. The "pot life" or working life, of the material is about 4 hours at 75°F and 50% humidity. The working life may become as little as 30 minutes when the ambient temperature exceeds 90°F. Tools should be cleaned with toluol immediately after use.

3.3 CRACKS AND JOINTS WITH LITTLE OR NO MOVEMENT

a. In the case of cracks which extend through vertical joints in alternate tiers and through the block in the intervening tier, where there is little or no movement, it is possible to make a repair having more structural strength than can be obtained with pointing mortars. The epoxy-resin compounds have proven very effective for this type of work. The material is ordinarily available as a thick, syrupy liquid or a heavy, non-sagging paste. The liquid may be mixed with dry silica sand or quartz sand to form a mortar for filling cracks from 3/8 inches to 3/4 inches wide. When these materials are properly cured they have greater bond and compressive strengths than the concrete itself. Examples of commercially available materials suitable for this use are: Fermagile '3' - liquid,
and Permagile No. 10 - paste, produced by the Permagile Corporation of America.

b. The width of the crack should determine the consistency of material to be used. For hairline cracks and slightly wider, the liquid form will usually suffice. If the crack is from 1/16 inch to 1/4 inch in width, the paste form is best. Cracks that vary in width from 3/8 inch to 3/4 inch should be repaired with epoxy mortar.

c. Cracks to be repaired must be clean to obtain the necessary bond with the epoxy compound. Loose mortar should be removed from joints. Cracks in individual blocks may need to be chiseled out to widen them enough to allow the material to penetrate to a depth of one inch.

d. Where the crack is wide enough to require epoxy mortar for repair, the surfaces to receive the mortar should be primed with the liquid mix. This may be done using a small swab.

e. To form mortar, the two components of the epoxy compound should be carefully mixed per the manufacturer's printed instructions. Clean silica or quartz sand should be stirred into the liquid in the ratio of two to three parts sand to one part liquid by volume. No more material should be mixed at one time than can be used immediately. The working life of the material after mixing varies from 30 minutes to one hour; the higher the temperature, the shorter the working life.

f. All forms of the material may be applied with knife or pointing trowel. The compound should be worked into the joint to a depth of one inch where possible. If penetration is made to a depth of only 1/2 inch or less, the repair is likely to be ineffective. The same procedure should be used on both the inner and outer faces of the wall.

g. Contact between epoxy compound and the skin should be avoided. Tools and hands can be cleaned by washing with soap and water or diacetone alcohol before the compound hardens.

4. REPAIR OF LEAKING JOINTS BELOW GRADE

a. Material for repairing leaking joints in masonry walls below grade should be a non-shrinking, quick setting, hydraulic cement. "Waterplug" hydraulic cement, produced by Standard Dry Wall Products, Inc. is an example of a commercially available material which is suitable for repairs below grade. Such a material is particularly well adapted to work where free surface water is present or where water is flowing through the joint.

b. The leaking joint should be chiseled out until it is approximately 3/4 inch by 3/4 inch in section. Sides of joint should be cut square; a V-type groove is not satisfactory. The joint should be flushed with water to remove dirt and cuttings.
c. The hydraulic cement should be mixed as per the manufacturer's instructions. The mixed material should have no slump. No more material should be mixed than can be put into place within 2 minutes. The mixed material will normally set hard within five minutes.

d. After mixing, the material should be pushed into the joint with a grooving tool or a round metal rod. The joint should be wet when the cement is applied. If water is running in the joint, the mixed cement should be in the palm of the hand until the heat of the chemical reaction can be felt. The cement should then be placed in the joint and held in place under pressure with a trowel for 2 or 3 minutes until hardened. The trowel can then be removed and the joint trimmed flush with the adjacent wall surface. If the joint is at the junction of floor and wall, the cement should be formed in a one inch cove.

5. SEALING LEAKING WALLS ABOVE GRADE

a. Concrete block walls above grade which leak, from wind-blown rain for example, can be sealed on the exterior with a clear silicone liquid. The material used should meet or exceed the requirements of interim Federal Specification SS-W-00110, Water Repellent, Colorless, Silicone Resin Base. The following are examples of commercially available, clear, silicone resin solutions which are suitable for treatment of masonry walls at Hanford:

   (1) "Daracone" - produced by Dewey & Almy Chemical Div. - W. R. Grace Co.
   (2) "Dehydratine 22" - produced by A.C. Horn Div. - Sun Chemical Corp.
   (3) "Siliclear" - produced by the National Paint Co.

b. The silicone liquid requires no thinning or mixing. It should be applied only to dry, clean surfaces free of old coatings. If the wall has been wet within the past 72 hours, or rain is expected within 24 hours after application, the material should not be applied. Before applying the liquid all cracks and crevices in the wall should be repaired and the wall brushed to remove dust and efflorescence.

c. The silicone liquid can be applied with a fine, hair-bristle paint brush, power spray, or garden spray. If applied by brush, the liquid should be flooded on the surface and not brushed out. A single wet coat is sufficient. The silicone can be removed from glass and tools with lacquer thinner or Naphtha. Safety precautions should be observed when using highly volatile solvents. Smoking should not be permitted.

d. Where sealing or waterproofing with other than a clear coating is desired, see Hanford Guide DG-32-AC, Selection of Paints for Ordinary
e. In some cases the source of leaks may be at the roof line from water draining from the roof. In such cases when it is important that there be no leaks and the cost can be justified, the use of gutters and downspouts should be considered.
DG-502-AC

GUIDE

FOR

DETERMINING ALLOWABLE LIVE LOADS

OVER BURIED PIPING
1. PURPOSE

The purpose of this guide is to assist in determining maximum wheel loads which can be allowed to pass over buried piping.

2. BACKGROUND

Under certain conditions, construction traffic and other heavy loads can damage or collapse buried piping. To prevent such damage, the field engineer needs to know if a pipe can safely support the load in question. If the pipe is not strong enough, protection can be provided, such as a simple bridge. In some cases, simply crossing the pipe at a point where the cover is more than 8 feet (see 3.1 below) will avoid the need for special protection.

This guide presents a method for quickly determining the load a buried pipe can safely carry. The method applies to pipes laid without cradles or encasement and with no paving on the ground surface. This method should not be used indiscriminately for design of piping.

3. DETERMINING THE LOAD ON THE PIPE

3.1 PIPES WITH MORE THAN EIGHT FEET OF COVER

Live loads may be neglected for pipes with more than eight feet of earth cover over the top of the pipe. The amount of live load transmitted to pipes with more than eight feet of cover is generally considered to be negligible.

3.2 PIPES WITH EIGHT FEET TO TWO FEET OF COVER

A tabulation of dead loads from earth cover for nominal pipe sizes is provided in Table I. The loads per lineal foot of pipe are based on the maximum conditions of trench width and 120 lbs/cu ft material (sand and gravel) using the Marston formula $W_c = C_d w B_d^2$. 

-1-
TABLE I
DEAD LOAD FROM EARTH COVER ON UNDERGROUND PIPES

Loads are shown in pounds per lineal foot of pipe.

<table>
<thead>
<tr>
<th>DEPTH OF COVER FEET</th>
<th>NOMINAL PIPE DIAMETER - INCHES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>145</td>
</tr>
<tr>
<td>3</td>
<td>220</td>
</tr>
<tr>
<td>4</td>
<td>300</td>
</tr>
<tr>
<td>5</td>
<td>380</td>
</tr>
<tr>
<td>6</td>
<td>460</td>
</tr>
<tr>
<td>7</td>
<td>540</td>
</tr>
<tr>
<td>8</td>
<td>620</td>
</tr>
</tbody>
</table>

These figures apply to both rigid and flexible pipes buried in ditches or covered by embankment for the purpose of determining the dead load on existing pipes. They should not be used indiscriminately for new design.

The following figures may be used in calculating the percentage of wheel loads transmitted to underground pipes.

**TABLE II**

PERCENTAGE OF WHEEL LOADS TRANSMITTED TO UNDERGROUND PIPES
(Figures show percentage of wheel load applied to one linear foot of pipe)

| DEPTH OF COVER (FEET) | 3  | 4  | 5  | 6  | 8  | 10 | 12 | 15 | 18 | 21 | 24 | 27 | 30 | 33 | 35 | 39 | 42 | 48 | 54 | 60 |
|-----------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 1                     | 15.2| 18.6|25.6|30.0|34.6|40.0|45.2|49.6|52.8|54.4|56.0|57.2|58.0|58.3|59.6|59.7|60.0|60.3|60.6|
| 2                     | 7.0 | 8.5 |11.4|14.0|16.6|19.2|23.0|26.4|30.0|31.2|33.6|35.6|37.4|39.0|40.0|40.9|42.6|43.6|44.6|
| 3                     | 3.5 | 4.0 | 5.8 | 7.2 | 8.6 |10.4 |12.8 |15.0 |17.2 |18.6 |20.4 |22.2 |23.6 |25.0 |25.8 |26.0 |26.6 |28.0 |29.4 |
| 4                     | 2.0 | 2.4 | 3.4 | 4.2 | 5.0 | 6.2 | 7.8 | 9.2 |10.6 |11.6 |13.0 |14.4 |15.8 |17.0 |17.6 |17.7 |18.0 |19.7 |21.4 |
| 5                     | 1.4 | 1.8 | 2.4 | 2.8 | 3.4 | 4.2 | 5.2 | 6.2 | 7.2 | 7.8 | 8.8 | 9.8 |10.6 |11.6 |12.2 |12.4 |12.7 |14.0 |15.3 |
| 6                     | 0.9 | 1.2 | 1.6 | 2.0 | 2.2 | 2.8 | 3.6 | 4.2 | 5.0 | 5.6 | 6.2 | 7.0 | 7.6 | 8.4 | 8.6 | 8.8 | 9.3 |10.7 |12.0 |
| 7                     | 0.3 | 0.5 | 1.0 | 1.4 | 1.6 | 2.0 | 2.6 | 3.2 | 3.8 | 4.2 | 4.6 | 5.2 | 5.8 | 6.4 | 6.5 | 6.6 | 6.7 | 7.7 | 8.7 |
| 8                     | 0.2 | 0.4 | 0.8 | 1.0 | 1.2 | 1.6 | 2.0 | 2.4 | 2.8 | 3.2 | 3.6 | 4.0 | 4.4 | 4.6 | 5.0 | 5.1 | 5.3 | 6.0 | 6.7 |

The figures include an impact factor of 2.0 and are taken from Vitrified Clay Pipe Engineering Handbook, Clay Pipe Institute, 1956, and "Underground Conduits - An Appraisal of Modern Research", MG Spangler, ASCE Paper No. 2337, 1947. The figures apply to one vehicle with wheels at least 6 feet apart measured along the axle. The wheel load (as in the example) is 1/2 of the axle load. The wheel load may be on dual tires but is still considered one wheel.

**EXAMPLE:** Find the total load per ft on a 24" pipe with 5 ft of cover and a 20,000 lb wheel load (i.e. 1/2 of a 40,000 lb axle load).

Dead Load (from Table I) 2010 lbs/ft
Live Load (from Table II) is 7.3% of 20,000 = 1560 lbs/ft

Total Load = 3570 lbs/ft
3.3 PIPES WITH LESS THAN TWO FEET OF COVER

Pipes 6" diameter and larger with less than two feet of cover, regardless of pipe material, should be barricaded to prevent heavy construction loads from passing over them except at designated crossings where protection is provided.

4. ALLOWABLE LOADS FOR BURIED PIPING

After the total load (dead load + live load) has been determined by procedure shown in Section 3.2, determine if the pipe can safely carry the total load from the following tables.

4.1 ALLOWABLE LOADS FOR VITRIFIED CLAY PIPE

TABLE III

| INSIDE PIPE DIA INCHES | CLAY SEWER PIPE ASTM C261 STANDARD STRENGTH | | CLAY SEWER PIPE ASTM C278 EXTRA STRENGTH |
|------------------------|----------------------------------|----------------------------------|
|                        | SHELL THICKNESS | ALLOWABLE LOAD LBS/ LIN FT | SHELL THICKNESS | ALLOWABLE LOAD LBS/ LIN FT |
| 4                      | 1/2              | 1000                      | 5/8              | 2000                      |
| 6                      | 5/8              | 1000                      | 11/16             | 2000                      |
| 8                      | 3/4              | 1000                      | 7/8              | 2000                      |
| 10                     | 7/8              | 1100                      | 1                | 2000                      |
| 12                     | 1                | 1200                      | 1-3/16            | 2250                      |
| 15                     | 1-1/4            | 1400                      | 1-1/2             | 2750                      |
| 18                     | 1-1/2            | 1700                      | 1-7/8             | 3300                      |
| 21                     | 1-3/4            | 2000                      | 2-1/4             | 3850                      |
| 24                     | 2                | 2400                      | 2-1/2             | 4400                      |
| 27                     | 2-1/4            | 2750                      |                   |                           |
| 30                     | 2-1/2            | 3200                      |                   |                           |
| 33                     | 2-5/8            | 3500                      |                   |                           |
| 36                     | 2-3/4            | 3900                      | 3-1/2             | 6000                      |

These values are 2/3 of the minimum ultimate strength by the sand-bearing method thus giving a safety factor of 1.5. Data taken from ASTM Specifications C261 and C278.
### 4.2 Allowable Loads for Concrete Pipe

**Table IV**

<table>
<thead>
<tr>
<th>INSIDE PIPE DIA INCHES</th>
<th>CONCRETE SEWER PIPE</th>
<th>CONCRETE CULVERT PIPE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ASTM C14 PLAIN</td>
<td>ASTM C75 REINF (PRE-1957)</td>
</tr>
<tr>
<td></td>
<td>STD</td>
<td>STRENGTH</td>
</tr>
<tr>
<td>Shell Thick. Load lbs/</td>
<td>Inches</td>
<td>Lin ft</td>
</tr>
<tr>
<td>4</td>
<td>9/16</td>
<td>1000</td>
</tr>
<tr>
<td>8</td>
<td>3/4</td>
<td>1300</td>
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<td>10</td>
<td>7/8</td>
<td>1400</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>1500</td>
</tr>
<tr>
<td>15</td>
<td>1-1/4</td>
<td>1750</td>
</tr>
<tr>
<td>18</td>
<td>1-1/2</td>
<td>2000</td>
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<tr>
<td>21</td>
<td>1-3/4</td>
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<td>24</td>
<td>2-1/8</td>
<td>2400</td>
</tr>
<tr>
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<tr>
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<td>42</td>
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<td></td>
</tr>
<tr>
<td>60</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

These values are 2/3 of the ultimate strength of the pipe by the sand bearing method, giving a safety factor of 1.5.

Pipe manufactured prior to 1957 would normally meet these specification values. In 1957 ASTM C75 and C76 were combined in C76 which has 5 classes with the following allowable loads in lbs/Lin ft:

- **Class I**: 1200 x internal diameter in feet
- **Class II**: 1500 x internal diameter in feet
- **Class III**: 2000 x internal diameter in feet
- **Class IV**: 3000 x internal diameter in feet
- **Class V**: 3750 x internal diameter in feet

Data taken from ASTM C14, C75 and C76.
### 4.3 ALLOWABLE LOADS FOR ASBESTOS-CEMENT SEWER PIPE

#### TABLE V-A (PRE-1958)

<table>
<thead>
<tr>
<th>INSIDE</th>
<th>ASBESTOS-CEMENT SEWER PIPE MANUFACTURED PRIOR TO 1958</th>
<th>CLASS 1</th>
<th>CLASS 2</th>
<th>CLASS 3</th>
<th>CLASS 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIPE</td>
<td>SHELL THICK.</td>
<td>ALLOW. LOAD lbs/lin ft</td>
<td>SHELL THICK.</td>
<td>ALLOW. LOAD lbs/lin ft</td>
<td>SHELL THICK.</td>
</tr>
<tr>
<td>DIA INCHES</td>
<td>4</td>
<td>0.39</td>
<td>4125</td>
<td>0.56</td>
<td>3690</td>
</tr>
<tr>
<td>5</td>
<td>0.41</td>
<td>3350</td>
<td>0.64</td>
<td>3850</td>
<td>0.74</td>
</tr>
<tr>
<td>6</td>
<td>0.42</td>
<td>2880</td>
<td>0.66</td>
<td>4100</td>
<td>0.74</td>
</tr>
<tr>
<td>8</td>
<td>0.43</td>
<td>2100</td>
<td>0.72</td>
<td>4500</td>
<td>0.79</td>
</tr>
<tr>
<td>10</td>
<td>0.50</td>
<td>2580</td>
<td>0.56</td>
<td>3690</td>
<td>0.65</td>
</tr>
<tr>
<td>12</td>
<td>0.54</td>
<td>2370</td>
<td>0.64</td>
<td>3850</td>
<td>0.74</td>
</tr>
<tr>
<td>14</td>
<td>0.58</td>
<td>2200</td>
<td>0.73</td>
<td>3920</td>
<td>0.84</td>
</tr>
<tr>
<td>16</td>
<td>0.62</td>
<td>2120</td>
<td>0.82</td>
<td>4050</td>
<td>0.94</td>
</tr>
<tr>
<td>18</td>
<td>0.65</td>
<td>2030</td>
<td>0.90</td>
<td>4140</td>
<td>1.03</td>
</tr>
<tr>
<td>20</td>
<td>0.69</td>
<td>2290</td>
<td>0.94</td>
<td>4280</td>
<td>1.13</td>
</tr>
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<td>24</td>
<td>0.75</td>
<td>2340</td>
<td>1.06</td>
<td>4550</td>
<td>1.31</td>
</tr>
<tr>
<td>30</td>
<td>0.96</td>
<td>2980</td>
<td>1.24</td>
<td>5000</td>
<td>1.64</td>
</tr>
<tr>
<td>36</td>
<td>1.15</td>
<td>3500</td>
<td>1.41</td>
<td>5400</td>
<td>1.93</td>
</tr>
</tbody>
</table>

#### TABLE V-B (POST-1958)

<table>
<thead>
<tr>
<th>INSIDE</th>
<th>ASBESTOS-CEMENT SEWER PIPE MANUFACTURED AFTER 1958</th>
<th>CLASS 1500</th>
<th>CLASS 2400</th>
<th>CLASS 3300</th>
<th>CLASS 4000</th>
<th>CLASS 5000</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIPE</td>
<td>SHELL THICK.</td>
<td>ALLOW. LOAD lbs/lin ft</td>
<td>SHELL THICK.</td>
<td>ALLOW. LOAD lbs/lin ft</td>
<td>SHELL THICK.</td>
<td>ALLOW. LOAD lbs/lin ft</td>
</tr>
<tr>
<td>DIA INCHES</td>
<td>6</td>
<td>0.46</td>
<td>1500</td>
<td>0.49</td>
<td>2400</td>
<td>0.57</td>
</tr>
<tr>
<td>8</td>
<td>0.51</td>
<td>1500</td>
<td>0.52</td>
<td>2400</td>
<td>0.61</td>
<td>3300</td>
</tr>
<tr>
<td>10</td>
<td>0.56</td>
<td>1500</td>
<td>0.58</td>
<td>2400</td>
<td>0.68</td>
<td>3300</td>
</tr>
<tr>
<td>12</td>
<td>0.61</td>
<td>1500</td>
<td>0.63</td>
<td>2400</td>
<td>0.75</td>
<td>3300</td>
</tr>
<tr>
<td>14</td>
<td>0.66</td>
<td>2400</td>
<td>0.81</td>
<td>3300</td>
<td>0.95</td>
<td>4000</td>
</tr>
<tr>
<td>16</td>
<td>0.73</td>
<td>2400</td>
<td>0.91</td>
<td>3300</td>
<td>1.01</td>
<td>4000</td>
</tr>
<tr>
<td>18</td>
<td>0.77</td>
<td>2400</td>
<td>0.96</td>
<td>3300</td>
<td>1.06</td>
<td>4000</td>
</tr>
<tr>
<td>20</td>
<td>0.81</td>
<td>2400</td>
<td>1.05</td>
<td>3300</td>
<td>1.16</td>
<td>4000</td>
</tr>
<tr>
<td>24</td>
<td>0.89</td>
<td>2400</td>
<td>1.17</td>
<td>3300</td>
<td>1.30</td>
<td>4000</td>
</tr>
<tr>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>36</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The values in Tables V-A and V-B are based on ultimate strength by the 3-edge bearing method which is normally 2/3 of the ultimate strength of the pipe as installed, thus giving a safety factor of 1.5.
4.4 ALLOWABLE LOADS FOR ASBESTOS-CEMENT PRESSURE PIPE

**TABLE VI**

<table>
<thead>
<tr>
<th>INSIDE PIPE DIA</th>
<th>INSIDE PIPE THICKNESS</th>
<th>ALLOW. LOAD #/Lin ft</th>
<th>CLASS 100</th>
<th>CLASS 150</th>
<th>CLASS 200</th>
</tr>
</thead>
<tbody>
<tr>
<td>INCHES</td>
<td>SHELL THICK. Inches</td>
<td>LIN FT</td>
<td>SHELL THICK. Inches</td>
<td>SHELL THICK. Inches</td>
<td>SHELL THICK. Inches</td>
</tr>
<tr>
<td>4</td>
<td>0.445</td>
<td>4100</td>
<td>0.510</td>
<td>5400</td>
<td>0.660</td>
</tr>
<tr>
<td>6</td>
<td>0.530</td>
<td>3900</td>
<td>0.610</td>
<td>5400</td>
<td>0.780</td>
</tr>
<tr>
<td>8</td>
<td>0.590</td>
<td>3700</td>
<td>0.710</td>
<td>5500</td>
<td>0.920</td>
</tr>
<tr>
<td>10</td>
<td>0.660</td>
<td>3700</td>
<td>0.910</td>
<td>7000</td>
<td>1.095</td>
</tr>
<tr>
<td>12</td>
<td>0.750</td>
<td>4000</td>
<td>1.040</td>
<td>7600</td>
<td>1.260</td>
</tr>
<tr>
<td>14</td>
<td>0.820</td>
<td>4400</td>
<td>1.190</td>
<td>8600</td>
<td>1.470</td>
</tr>
<tr>
<td>16</td>
<td>0.905</td>
<td>4800</td>
<td>1.310</td>
<td>9200</td>
<td>1.670</td>
</tr>
<tr>
<td>18</td>
<td>-</td>
<td>5200</td>
<td>-</td>
<td>10100</td>
<td>-</td>
</tr>
<tr>
<td>20</td>
<td>-</td>
<td>5600</td>
<td>-</td>
<td>10900</td>
<td>-</td>
</tr>
<tr>
<td>24</td>
<td>-</td>
<td>6300</td>
<td>-</td>
<td>12700</td>
<td>-</td>
</tr>
<tr>
<td>30</td>
<td>-</td>
<td>7500</td>
<td>-</td>
<td>15900</td>
<td>-</td>
</tr>
<tr>
<td>36</td>
<td>-</td>
<td>8800</td>
<td>-</td>
<td>19600</td>
<td>-</td>
</tr>
</tbody>
</table>

These values are based on the ultimate strength by the 3-edge bearing which is normally 2/3 of the ultimate strength of the pipe as installed, thus giving a safety factor of 1.5. Load data taken from ASTI C296. Thickness data from Johns-Manville literature which lists up to 18" only. Wall thicknesses are not specified in ASTI C296; hence no figures are available for sizes 18"-36".

4.5 ALLOWABLE LOADS FOR ASBESTOS-CEMENT CONDUIT

**TABLE VII**

<table>
<thead>
<tr>
<th>NOMINAL INSIDE DIAMETER INCHES</th>
<th>ASBESTOS-CEMENT CONDUIT - FED SPEC W-C-571 Type II SHELL THICKNESS INCHES</th>
<th>ALLOWABLE LOAD LBS/ LIN FT</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>.32</td>
<td>1200</td>
</tr>
<tr>
<td>.5</td>
<td>.32</td>
<td>1110</td>
</tr>
<tr>
<td>4</td>
<td>.32</td>
<td>1200</td>
</tr>
<tr>
<td>5</td>
<td>.35</td>
<td>900</td>
</tr>
<tr>
<td>6</td>
<td>.35</td>
<td>800</td>
</tr>
</tbody>
</table>

These values are based on the minimum ultimate strength (no cracking) of a 2-plate bearing test, similar to the 3-edge bearing test. The strength by this method is normally 2/3 of the ultimate strength as installed thus giving a safety factor of 1.5. Some commercial conduit is manufactured with thicker walls but strength data is not published. The above figures should be used for all asbestos-cement conduit which, in the case of thicker walled conduit will give a greater factor of safety.
ALLOWABLE LOADS FOR CORRUGATED METAL CULVERT AND SEWER PIPE

### TABLE VIII

<table>
<thead>
<tr>
<th>NOMINAL PIPE DIA INCHES</th>
<th>Corrugated Metal Pipe 2-2/3&quot; Pitch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>16 Ga</td>
</tr>
<tr>
<td>8</td>
<td>7500</td>
</tr>
<tr>
<td>10</td>
<td>7500</td>
</tr>
<tr>
<td>12</td>
<td>7500</td>
</tr>
<tr>
<td>15</td>
<td>7500</td>
</tr>
<tr>
<td>18</td>
<td>7500</td>
</tr>
<tr>
<td>21</td>
<td>7500</td>
</tr>
<tr>
<td>24</td>
<td>3700</td>
</tr>
<tr>
<td>30</td>
<td>9,400</td>
</tr>
<tr>
<td>36</td>
<td>5,600</td>
</tr>
<tr>
<td>42</td>
<td>11,000</td>
</tr>
<tr>
<td>48</td>
<td>8,400</td>
</tr>
<tr>
<td>54</td>
<td>9,800</td>
</tr>
<tr>
<td>60</td>
<td>9,300</td>
</tr>
<tr>
<td>66</td>
<td>9,500</td>
</tr>
<tr>
<td>72</td>
<td>11,000</td>
</tr>
</tbody>
</table>

These are arbitrary values computed from maximum allowable height of fill shown in loading tables in "Handbook of Drainage and Construction Products". Armco Drainage and Metal Products, Inc., 1955; which states that these fill heights produce approximately a 5% deflection or a safety factor of about 4.

ALLOWABLE LOADS FOR STEEL PIPE

Allowable loads on buried steel pipes up to about 24 inches in diameter can be computed based on the ability of the pipe to sustain a vertical load by ring action alone. Pipes over about 24 inch diameter, with the wall thicknesses normally used, will not carry heavy loads from ring action alone without undue deflection; consequently, side support from earth pressure must be assumed in computing allowable loads. In order for the earth to provide a predictable amount of side support, it must have been compacted around the pipe to a high density, say 95 to 98% of maximum density as defined in ASTM D698. Since much pipe at Hanford has been installed with little or no tamping of backfill around the pipe, it becomes difficult, if not impossible, to assign a value to side support. In the worst condition, a buried pipe could be without side support entirely. For this reason, the following table is based on ring strength alone with no credit given to side support. Because no side support is credited, the table will indicate, in some cases, that the pipe will deflect more than 2% under the dead load already imposed on it. It is recommended that protection be required for those sizes which the table indicates will not carry (without undue deflection) the dead load or the dead load plus live load in question and for sizes not shown in the table. Pipes with more than eight feet of cover will not be appreciable affected by surface live loads and will not require protection. (See Section 3.1)
### TABLE II

<table>
<thead>
<tr>
<th>Nominal Pipe Dia Inches</th>
<th>Wall Thickness (or Sch)</th>
<th>Allow. Load Lbs/ Lin Ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>.237 Sch 40</td>
<td>10,000</td>
</tr>
<tr>
<td>5</td>
<td>.250 Sch 40</td>
<td>10,000</td>
</tr>
<tr>
<td>6</td>
<td>.280 Sch 40</td>
<td>10,000</td>
</tr>
<tr>
<td>8</td>
<td>.250 Sch 20</td>
<td>8,300</td>
</tr>
<tr>
<td>8</td>
<td>.322 Sch 40</td>
<td>9,200</td>
</tr>
<tr>
<td>10</td>
<td>.250 Sch 20</td>
<td>7,300</td>
</tr>
<tr>
<td>10</td>
<td>.307 Std</td>
<td>14,600</td>
</tr>
<tr>
<td>10</td>
<td>.365 Sch 40</td>
<td>18,700</td>
</tr>
<tr>
<td>12</td>
<td>.250 Sch 20</td>
<td>5,100</td>
</tr>
<tr>
<td>12</td>
<td>.330 Std</td>
<td>13,700</td>
</tr>
<tr>
<td>12</td>
<td>.375 Sch 40</td>
<td>17,500</td>
</tr>
<tr>
<td>14</td>
<td>.250 Sch 10</td>
<td>3,800</td>
</tr>
<tr>
<td>14</td>
<td>.312 Sch 20</td>
<td>7,500</td>
</tr>
<tr>
<td>14</td>
<td>.375 Sch 30</td>
<td>13,100</td>
</tr>
<tr>
<td>16</td>
<td>.250 Sch 10</td>
<td>3,000</td>
</tr>
<tr>
<td>16</td>
<td>.312 Sch 20</td>
<td>5,600</td>
</tr>
<tr>
<td>16</td>
<td>.375 Sch 30</td>
<td>10,000</td>
</tr>
<tr>
<td>18</td>
<td>.250 Sch 10</td>
<td>2,440</td>
</tr>
<tr>
<td>18</td>
<td>.375</td>
<td>7,700</td>
</tr>
<tr>
<td>18</td>
<td>.437 Sch 30</td>
<td>12,700</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nominal Pipe Dia Inches</th>
<th>Wall Thickness (or Sch)</th>
<th>Allow. Load Lbs/ Lin Ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>.250 Sch 10</td>
<td>1,900</td>
</tr>
<tr>
<td>20</td>
<td>.375 Sch 20</td>
<td>6,250</td>
</tr>
<tr>
<td>20</td>
<td>.500 Sch 30</td>
<td>14,500</td>
</tr>
<tr>
<td>24</td>
<td>.250 Sch 10</td>
<td>1,250</td>
</tr>
<tr>
<td>24</td>
<td>.375 Sch 20</td>
<td>4,250</td>
</tr>
<tr>
<td>24</td>
<td>.500</td>
<td>10,000</td>
</tr>
<tr>
<td>30</td>
<td>.250</td>
<td>930</td>
</tr>
<tr>
<td>30</td>
<td>.375</td>
<td>3,000</td>
</tr>
<tr>
<td>30</td>
<td>.500 Sch 20</td>
<td>6,500</td>
</tr>
<tr>
<td>36</td>
<td>.250</td>
<td>850</td>
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<td>36</td>
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<td>36</td>
<td>.500</td>
<td>4,900</td>
</tr>
<tr>
<td>42</td>
<td>.375</td>
<td>1,750</td>
</tr>
<tr>
<td>42</td>
<td>.500</td>
<td>3,000</td>
</tr>
<tr>
<td>48</td>
<td>.500</td>
<td>3,000</td>
</tr>
<tr>
<td>48</td>
<td>.625</td>
<td>5,500</td>
</tr>
<tr>
<td>54</td>
<td>.500</td>
<td>2,000</td>
</tr>
<tr>
<td>54</td>
<td>.625</td>
<td>4,500</td>
</tr>
<tr>
<td>60</td>
<td>.500</td>
<td>2,500</td>
</tr>
<tr>
<td>60</td>
<td>.625</td>
<td>4,000</td>
</tr>
</tbody>
</table>

These values are based on an approximate 2% deflection. Data taken from "Design and Deflection Control of Buried Steel Pipe Supporting Earth Loads and Live Loads" Russell E. Barnard, ASTM Proceedings Vol. 57, 1957. Table applies to all types of steel pipe: welded, seamless, spiral welded, and to stainless, or other steels which have a modulus of elasticity of about 30 x 10^6 lb/in^2, regardless of yield or ultimate strength since deflection within the elastic limit is dependent on modulus of elasticity, not strength.

#### 4.8 ALLOWABLE LOADS FOR CAST IRON PIPE

The wide variance in types and thicknesses of cast iron pipe makes it impractical to tabulate allowable loads in this guide. The three-edge bearing strength of cast iron pipe can be calculated from the following formula.*

\[
W = \frac{t^2 R}{0.0795 (d+t)}
\]

W = crushing load in lbs/lineal foot by 3-edge bearing test

t = thickness of pipe, inches

d = internal diameter of the pipe, inches

R = modulus of rupture (psi) of the metal in the pipe

For pit cast pipe R = 31,000 psi

For centrifugally cast pipe R = 40,000 psi

The thickness "t" should be reduced to allow for foundry tolerance and corrosion allowance. See table and worked example below. The value "W" obtained from this formula, which is the crushing load, must be reduced for the ratio of 3-edge load capacity to actual installed load capacity and for a safety factor. The 3-edge ratio is approximately 1:1.5 and the safety factor should be 2.5x.

Multiplying W by 1.5 and dividing by 2.5, the allowable load per lineal foot of cast iron pipe, \( W_a \), becomes 0.6 of the value W obtained by the formula above. Expressed as a formula the allowable load is:

\[
W_a = 0.6 W
\]

TABLE X

MAXIMUM FOUNDRY TOLERANCES FOR CAST IRON PIPE*

<table>
<thead>
<tr>
<th>PIPE SIZE INCHES</th>
<th>MAXIMUM FOUNDRY TOLERANCE - INCHES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pit Cast Pipe</td>
</tr>
<tr>
<td>3-8</td>
<td>0.07</td>
</tr>
<tr>
<td>10-12</td>
<td>0.08</td>
</tr>
<tr>
<td>14-24</td>
<td>0.08</td>
</tr>
<tr>
<td>30-48</td>
<td>0.10</td>
</tr>
<tr>
<td>54-60</td>
<td>0.10</td>
</tr>
</tbody>
</table>

EXAMPLE: Find allowable load for 24" dia centrifugally cast iron pipe, class 22, wall thickness 0.68".

R = 40,000 psi

foundry tolerance = 0.08"

corrosion allowance = 0.08" (same for all sizes)

It is reasonable to assume that, in a short section of line, the full foundry tolerance plus full 0.08" corrosion would not occur on any one pipe and that these allowances might be cut in half. (From AMWA Cl01-57).

Therefore use \( t = 0.68" - 0.04" - 0.04" = 0.60" \)

\[
\text{Crushing Load, } W = \frac{t^2 R}{0.0795 (d+t)} = \frac{(0.60)^2 \times 40,000}{0.0795 (24 + 0.60)} = 7363 \text{ lb/ft}
\]

Allowable Load, \( W_a = 0.6W = 0.6 \times 7363 = 4418 \text{ lb/ft} \)

### ALLOWABLE LOADS FOR CONCRETE CYLINDER PIPE

<table>
<thead>
<tr>
<th>NOMINAL PIPE DIA INCHES</th>
<th>CONCRETE CYLINDER PIPE - FEDERAL SPECIFICATION SS-P-361 PIPE: PRESSURE, REINFORCED CONCRETE, PRETENSIONED REINFORCEMENT (STEEL CYLINDER TYPE) ALLOWABLE LOADS - ALL CLASSES</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>2500 lbs per lineal foot</td>
</tr>
<tr>
<td>16</td>
<td>3200 &quot; &quot; &quot; &quot;</td>
</tr>
<tr>
<td>18</td>
<td>3550 &quot; &quot; &quot; &quot;</td>
</tr>
<tr>
<td>20</td>
<td>4000 &quot; &quot; &quot; &quot;</td>
</tr>
<tr>
<td>24</td>
<td>4600 &quot; &quot; &quot; &quot;</td>
</tr>
<tr>
<td>30</td>
<td>5500 &quot; &quot; &quot; &quot;</td>
</tr>
<tr>
<td>36</td>
<td>6400 &quot; &quot; &quot; &quot;</td>
</tr>
<tr>
<td>42</td>
<td>7100 &quot; &quot; &quot; &quot;</td>
</tr>
</tbody>
</table>

Table is based on allowable load of 10 feet of earth cover and ability to resist "occasional concentrated external loadings which may occur under unusual field conditions" per American Pipe and Construction Co. Bulletin ACCP June, 1952.
INSTRUCTIONS FOR USE OF DG-510-AC
GUIDE FOR PREPARATION OF FORMAL SPECIFICATIONS
USED FOR PURCHASING PURPOSES

The technical requirements for materials or equipment may be prepared and presented to the seller in the form of either a Formal Specification or Informal Specification.

A Formal (HWS-numbered) Specification is a separate specification which is given an HWS-number and always maintains this separate identity. It is referenced in the Purchase Requisition and attached to it.

An Informal Specification is typed on the Purchase Requisition* and is transcribed directly on the Request for Quotation and later on the Purchase Order.

DG-510-AC was prepared to apply to the preparation of Formal Specifications. However, portions of this guide may be selected and applied to the preparation of Informal Specifications. To use the guide for this purpose the remarks under the following subject headings, taken from the guide, may be helpful.

2. FORMAL SPECIFICATIONS

This portion of the guide helps to answer the question - When should a Formal Specification be prepared for procurement? If a Formal Specification is not required the Informal Specification would state the technical requirements, under "Description" on the Purchase Requisition.

3. NATIONALLY RECOGNIZED SPECIFICATIONS

This portion of the guide applies to both Formal and Informal Specifications.

*For details concerning Purchase Requisitions see


(2) Instructions for Preparing Purchase Requisitions - (Issued by Purchasing & Stores, CE&UO).

-1- (Continued)
4. UNIFORM FORMAT

This portion of the guide pertains to the general arrangement and the numbering system of the subject headings and sub-headings, which cover the technical requirements of the Formal Specifications.

In preparation of certain Informal Specifications, it may be appropriate to place the technical requirements under subject headings and sub-headings. When this is done, use appropriate headings with the numbering system and arrangement as shown in the guide and in Appendix A. In such cases the Approval Sheet and the Table of Contents are not to be used.

5. REVISIONS

This section does not apply to Informal Specifications since the contents of this portion pertain only to Formal Specifications.

6. SOME IMPORTANT ITEMS TO CONSIDER IN PREPARATION OF SPECIFICATIONS

This portion of the guide applies to both Formal and Informal Specifications.
DG-510-AC

GUIDE FOR PREPARATION OF FORMAL SPECIFICATIONS

USED FOR

PURCHASING PURPOSES
1. **SCOPE**

Formal (HWS-numbered) specifications discussed in this Guide are those which state the technical requirements for materials or equipment to be purchased on a competitive basis.

The purposes of this guide are, (1) to provide assistance in the preparation of specifications of this type and, (2) to provide a Uniform Format for plant wide use when these specifications are prepared.

This guide does not cover specific technical requirements for any particular specification. Instead it is pointed in a general direction to discuss the following subjects:

   a. Formal specifications.
   b. Nationally recognized specifications.
   c. Uniform Format.
   d. Revisions.
   e. Some important items to consider in preparation of specifications.

2. **FORMAL SPECIFICATIONS**

To determine, when to prepare a formal (HWS-numbered) specification for procurement requires the use of judgement which must be applied to each individual case. The following are some guides to assist in deciding when to prepare a formal specification for procurement.

   a. When ordering engineered equipment, which is defined as any item to be purchased according to special predetermined design. This includes all items fabricated in shops as specials.

   b. When ordering manufacturer's stock items which are to be modified extensively or which require that special or unusual tests be made before acceptance.

   c. When ordering a "system" which is made up of many different parts combined into a unit. An instrument panel system is an example.

   d. When detailed written requirements are lengthy (4 or more pages).
e. When ordering to meet strictly functional requirements. A functional specification states the scope requirements, the tasks, job, the manner in which the specific product is to perform, and provides for the seller to furnish the detailed design. A functional specification is ideal when a non-existing product is to be procured and the seller is to furnish the detailed design.

Note: (Where an invitation permits bidders to draft their own plans and specifications, from which the buyer could select the product considered most preferable - the Comptroller General, U.S. has held, that such procedures do not comply with the requirements for competitive bidding. Competitive bidding statutes require a basis for exact comparison of bids. Requirements must be sufficiently definite to assure, that every bid made in compliance will be for substantially the same product.)

3. NATIONALLY RECOGNIZED SPECIFICATIONS

Those specifications prepared by various national technical and governmental organizations, which are accepted for plant use, are listed in "SDC 1,2 Standard Design Criteria for Codes, Standards, and Specifications". (Also see G-1-1 Guide for Selecting and Locating National Codes and Specifications'.)

In the preparation of a specification for a particular job, when appropriate use the national specifications - refer to them by title, reference number and date, but be sure the specifications referenced fit the requirements. National specifications are prepared for broad usage and require that certain things be designated. Often a specific type or grade must be selected; also, other choices must frequently be specified. Many national specifications contain "when" clauses. For example - one specification states - "when appurtenances are installed the use of appurtenances as specified herein is required." This means unless actually specified, the appurtenances will not be supplied for installation. To prevent "pitfalls", it is important to become thoroughly familiar with the specifications being referenced.

In cases where some specific requirements may be different than those stated in the national specification but other points are applicable - prepare the job specification by proper identification reference (title, number and date) to the national specification, and then state the necessary modifications. Sellers are familiar with national specifications; when such specifications are referenced even with modifications, the seller can quickly notice the differences.
4. **UNIFORM FORMAT**

Appendix A is a general sample showing the Uniform Format. It designates the form, general arrangement, and numbering system to be used in the preparation of formal (HWS-numbered) specifications used for procurement.

The purpose of the format is to provide for plant-wide uniformity in presenting specifications of this type. The sample format shows:

a. A Sample Approval Sheet for these specifications, with the accompanying information.

b. Sample pages for the Table of Contents, which list the page numbers where the different sections are located. When more than one page is necessary, the pages are numbered with Roman Numerals. These numbers are placed at the bottom of the page in the center.

c. Sample pages for general arrangement and numbering system of technical portion.

Although specific title headings are shown, these are only used to indicate the arrangement and numbering system and do not mean that a specification should have these specific headings. The title headings and the statements of the detailed requirements are the responsibility of the specification writer. Sections of the specification are to be given titles and consecutively numbered with Arabic figures as shown. Also, sub-sections and additional sub-divisions are to be identified as shown.

Border margins should be arranged to fit the methods of reproducing and binding of final specifications. In the sample the uniform margin is shown on the left of the pages. When pages are to be reproduced back to back, every second sheet should be provided with the same minimum margin on the right side.

Pages are Arabic numbered consecutively starting with the first page of the technical portion. The page numbers are shown at the bottom of the sheet in the center. Each page carries the HWS number at the lower right hand corner; when a page is revised the latest revision date for that particular page is shown at the lower left hand corner.
As soon as a specification is approved and reproduced it becomes a matter of record and the specification is placed in the HAPO permanent files.

If a specification change is made by means of purchase requisition or purchase order, and the specification is not revised, it remains unchanged in the permanent files. In this case anyone looking up the specifications for that particular job would not have the complete specification story.

It is important that all changes to a specification be properly recorded. This requires that the specification be revised whenever a change is made.

When a specification is revised, each revised sheet is identified by the latest revision date, which is recorded on each sheet affected - (See Appendix A, bottom page 12 - location of revision is identified on each page). Also, the revision number and date is shown on the Approval Sheet. (See Appendix A, page 7 for location of the revision note).

6. SOME IMPORTANT ITEMS TO CONSIDER IN PREPARATION OF SPECIFICATIONS

To prevent misinterpretations, it is extremely important that every effort possible be made to present a good, clear and complete specification. The following are some items to follow when specifications are prepared.

a. Realize the importance of preparing a good specification.

b. Refer to nationally recognized specifications and Hanford Engineering Standard Specifications whenever they apply. Become familiar with the detailed contents of all referenced specifications. If the specification being prepared requires reference to more than one national specification be sure that conflicts are eliminated.

c. State requirements completely, clearly, precisely and concisely. Specifications should be specific - they should not imply. Tell the bidder what is wanted, not how he should do his work.

d. Pattern the specification for the particular job - use other similar specifications as guides, but do not copy, unless the requirements are known to be proper and adequate for your particular job.
e. Write what you mean and mean what you write - if you do not mean it - do not write it.

f. Specify the minimum requirements consistent with good design principles - over specifying costs more. If the need or proposed quality is doubtful - raise the question - Is this actually required? If the answer is "Yes" the item can be justified.

g. Work closely with those who have the technical "know-how" and with those who have the operating responsibility and the maintenance responsibility of the final product.

h. Work closely with Purchasing. They deal constantly with sellers - they can be helpful to point out likely points of trouble in the procurement phase. The number of revisions and delays may be fewer by obtaining their comments before the specification is typed in final form.

i.* Omit items concerning instruction to bidders; qualifications of bidders; their previous experience, etc. Omit all contract matters, e.g. delivery date, date for submitting shop drawings, warranties, etc.

j.* Omit quantities, shipping instructions, etc.

k. Omit location and sizes which should be shown on detailed design drawings.

l. Omit intra-company instructions, e.g. - Bids shall be submitted to Engineering for review and evaluation. Omit instructions to inspector.

m. Omit names of Company employees.

n. Check final specification against final drawings.

Specification shall not duplicate information contained on drawings. Items known to properly be a part of the purchase requisition, but which are not in formal specifications, should be listed and sent for inclusion in requisition.

o. Have specification checked by another person who has the job knowledge.

*These items must be specified but the specification is not the place to do this.
p. Specify all tests which will be required and state details.

q. State the requirements to obtain competitive bids. Do not write a restrictive specification which limits the product to one seller's design.

r. Make the specification complete. State all the requirements, include all service conditions. Additional requirements specified after award will usually cost considerably more than if included before the bids were requested.

s. Refer to the party who will supply the purchased item as the "seller", and the party making the purchase as the "buyer".
APPENDIX A

SAMPLE APPROVAL SHEET FOR SPECIFICATIONS
USED FOR PURCHASING
(This sample approval sheet is a guide only and should be modified as necessary.)

HWS (Number)

SPECIFICATION

FOR

PROCUREMENT OF

(Title - When applicable, include Building and Project Number)

(Original issue date)

(Rev. No. & date)
(Give general location of revision-e.g. Sec. 7 and 8b(2)-page 3)

Prepared by General Electric Company
(Name of Component Preparing Specification)

Prepared by. Date,

Approved for General Electric Company

(Name of Design Component) Date

(Name of Project Management Component) Date

(Name of Customer Component) Date
SAMPLE - TABLE OF CONTENTS
(Only use when specification contains sufficient number of pages to justify. Not recommended for less than 6 pages)

HWS (Number)

SPECIFICATION FOR PROCUREMENT OF
(TITLE)

TABLE OF CONTENTS

<table>
<thead>
<tr>
<th></th>
<th>SCOPE</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DESCRIPTION</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>STANDARDS OF DESIGN AND CONSTRUCTION</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>GENERAL</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>MATERIALS</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>5.1 CARBON STEEL</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>5.2 STAINLESS STEEL</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>VESSEL</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>APPURTENANCES</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>7.1 SUPPORTS</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>7.2 VALVES</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>7.3 PIPING</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>MOTORS</td>
<td>3</td>
</tr>
</tbody>
</table>
9. Fabrication
Page No. 3 & 4

10. Testing
Page No. 4
SAMPLE - SHOWING GENERAL ARRANGEMENT & NUMBERING SYSTEM OF TECHNICAL PORTION

HWS (Number)

SPECIFICATION

FOR

PROCUREMENT OF

(TITLE)

(Allow ample space between spec. title and 1st section approximately 6 spaces)

1. **SCOPE (*)** All (*) are "Section" Titles - Identify with number - capitalize and underline. )

   (General description of over-all work included in specification. )

2. **DESCRIPTION (*)**

   (When equipment consists of several component parts which need be identified separately, the descriptions of each may be desirable. )

   a. e.g. - Describe Vessel

      (To identify use lower-case letters. Such groupings should be used only when information or requirements are divided into 2 or more groups. )

   b. e.g. - Describe Supports

---

-1-  HWS (Number)

---

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Appendix A - (Cont'd)  CAPE-1072-

SAMPLE - SHOWING GENERAL ARRANGEMENT & NUMBERING SYSTEM OF TECHNICAL PORTION - (CONT'D)

3. STANDARDS OF DESIGN AND CONSTRUCTION (*)

   a. (e.g. - For Vessel - ASME Boiler and Pressure Vessel Code - Sec. VIII Unfired Pressure Vessels - 1962.)

   b. (e.g. - For Supports - American Institute of Steel Construction, Specification for Design, Fabrication & Erection of Structural Steel for Buildings - 1961)

4. GENERAL (*)

   (Additional items covering information of a general nature may be included. When only one item is necessary, the Section Title should be more specific.)

5. MATERIALS (*) (Often a Section Title similar to "Materials" is broad and general requiring several main sub-sections of equal importance, i.e. the following Sub-Sections 5.1 - 5.2 and 7.1 through 7.3)

   5.1 CARBON STEEL (**) (All (**) are sub-section titles - number as shown - capitalize but do not underline.)

   a. (When additional groupings are needed under sub-section headings - use this system of identification. Such groupings should be used only when information or requirements are divided into 2 or more groups of equal importance.)

   b. ........................................

      (1) (When additional sub-groupings are required, use this system of identification. Only use for 2 or more groups.)

         (a) (Use this identification if needed. Only use for 2 or more such groups.)

         (b) ......................................

         -2- HWS (Number)

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5.2 STAINLESS STEEL (**)
   a.  
   b.  

6. VESSEL

7. APPURTENANCES (*)
   7.1 SUPPORTS (**)
   7.2 VALVES (**)
      a.  
      b.  

7.3 PIPING (**)

8. MOTORS (*)
   a.  
   b.  
      (1)  
      (2)  

9. FABRICATION (*)
   a.  

(specific location of revision)

#Title change
##Revised line
Revised (Date) -3- HWS (Number)

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Appendix A - (Cont'd)  CAPE-1072-

SAMPLE - SHOWING GENERAL ARRANGEMENT & NUMBERING SYSTEM OF TECHNICAL PORTION - (CONT'D)


b. ........................................

(1) ........................................

(2) ........................................

(a) ........................................

(b) ........................................

10. TESTING (*)

........................................
DG-700-D

GUIDE FOR USE OF STANDARD DESIGN CRITERIA AND PREPARATION OF SUPPLEMENTAL CRITERIA
1. **GENERAL**

   a. The purpose of this guide is to explain the use of the Standard Design Criteria* and to assist in the development and preparation of design criteria for specific projects.

   b. The information in this guide is for design purposes only. It is not intended to cover the internal distribution of copies of drawings, ATP's, BPF's, as-builts, etc., or similar items of administrative procedure for the individual departments or operations.

   c. Individual department instructions on such items as acceptance test procedures, as-built drawings, shop drawings, etc., shall take precedence over this guide when deemed necessary by the using department.

   d. The complete criteria for an individual project consists of the Standard Design Criteria, developed for items common to major projects, plus the supplemental criteria covering the specific items for the project.

2. **SCOPE OF THE CRITERIA**

   The Standard Design Criteria,* an integral part of the Hanford Engineering Standards, contain basic instructions for the design of new, or major alterations to facilities for Hanford Atomic Products Operation. The criteria include specific requirements and modification of certain codes and specifications for such design of facilities at Hanford.

   They are prepared for use by design engineers, field inspectors, and maintenance engineers and shall not be used for construction specifications.

   The Standard Design Criteria are divided into several sections, each covering a portion of design. They are intended to be supplemented with individual criteria defining the other specific requirements which are not included in the Standard Design Criteria.

   The Hanford Standard Design Criteria are intended to adapt the AEC Design Criteria** to local conditions by clarifying and supplementing them, as required.

* See the Standard Design Criteria Book, HWS-10006

** Part 6300 of the AEC Manual, See Appendix IV of this guide for list of Chapters.
3. **USE OF STANDARD DESIGN CRITERIA**

The criteria are to be used in the design of all essentially permanent structures and facilities at Hanford. They are intended for use by HAPO designers and outside Architect-Engineers. (As used in this guide, the term "Architect-Engineer" means outside Architect-Engineers, only).

4. **INFORMATION TO BE FURNISHED TO ARCHITECT-ENGINEERS**

a. **General**

Any design job submitted to an Architect-Engineer will necessarily require additional specific information in the form of a supplemental design criteria.

The supplemental design criteria, which will be used as a part of an Architect-Engineer contract, requires a thorough and complete presentation of both "what is required" and "the desired results". The amount of effort used in developing such a design criteria will depend on the nature of the project. Criteria for projects involving production processes, for example, will contain special requirements for items not within the scope of the Standard Criteria. The criteria should contain the minimum essential elements, sufficiently definitive, to allow performance of the required services. Generally, the elements used in this presentation are engineering flow diagrams, material balance and process flow diagrams, general arrangement drawings and a comprehensive functional description of systems, utilities, occupancy and special features. Also, the description should include mention of special practices or procedures, such as safety, radiation, and contamination that are common to Hanford. The criteria, properly prepared, should permit the development of good design in reasonable time and at a reasonable cost.

Where classified matter is a part of the design, scope, or contract, it should be reviewed by proper plant security personnel prior to issue.

b. **Typical Supplemental Information**

The following is typical, but not necessarily all-inclusive, of the information which must be directed to the Architect-Engineer in the supplemental design criteria or by means of scope drawings.

1. The location of the facility.

2. Expected use of the facility including special, hazardous or unusual practices or requirements (safety, radiation, and contamination), and design service life, if known. The department safety specialist should be consulted for functional safety requirements.
(3) Layout and possibly topography. **CAPE-1072**

(4) Location, capacity and availability of existing outside services.

(5) Adjacent existing structures and facilities.

(6) Requirements for future expansion, when required.

(7) Information for process design.

(8) Environmental conditions, such as weather data, vibration, shock, heat, dust, etc., when required.

(9) List of applicable Hanford Standards and using department Engineering Standards.

(10) Any special requirements.

c. **Miscellaneous Additional Information**

(1) **Acceptance Test Procedures**

When it is adjudged necessary by the HAPO Design Engineer to require documented reports of special or involved testing, the Architect-Engineer should be instructed to prepare Acceptance Test Procedures (ATP). The Architect-Engineer must be informed which components will require ATP's and to what extent the ATP information is recorded. When necessary, the following or similar explanation and requirements should be included in the supplemental design criteria. The HAPO design engineer should review his Department Instruction on Acceptance Test Procedures for further information and AEC Procedure and Policy Guide No. 09.4, "Acceptance Test Procedure".

(a) **Definition**

An Acceptance Test Procedure differs from construction specification statements for functional testing in that it is prepared as a separate document which includes tests explained in the construction specification. Similar in form to a specification, an ATP outlines the steps to be followed by the Construction Contractor in demonstrating the acceptability of a new installation. The Acceptance Test Procedure form describes in detail the test to be performed and provides blank spaces for the insertion of the actual test results, and signature sheets for witnessing and approving the tests. The ATP must clearly establish who will conduct and record the tests and what special services, if any, will be offered by others.
The subject of an Acceptance Test Procedure may be a single piece of equipment, a portion of a process, a system comprised of a number of associated pieces of equipment, or a complete system of buildings.

(b) Special Services

Where facilities to be given an acceptance test include instruments, the ATP shall state that the instruments shall be calibrated before conducting the test. The calibration will be done by HAFPO forces, but should be referred to as being done by "others".

(c) Preparation

Final ATP's shall be prepared on masters for reproduction using the multilith process (medium or long run masters) and submitted for approval. Each ATP shall have a combination title and approval sheet with blank spaces for approval of the procedure, witnessing of the test, and approval and acceptance of the system being tested. Final ATP's shall bear signatures of the Architect-Engineer where appropriate. (See Appendix I of this guide for sample of approval sheet).

(2) As-Built Drawings

When the Architect-Engineer will be required to prepare as-built drawings, the supplemental design criteria must state the requirements.

As-builds may be required in either of two ways. The Architect-Engineer may be required to: 1) furnish as-built prints, or 2) furnish as-built prints and correct the tracings to as-built condition.*

When as-built prints, only, will be required, the following should be stated in supplemental criteria:

"The Architect-Engineer shall maintain two sets of as-built construction drawings and specifications at the job site. Drawings and specifications shall be marked to show the revisions and changes in design experienced during the course of construction. Minor items which need not be noted are:

(a) Minor mechanical, electrical, or instrument equipment locations when the change in location is not significant and when the locations are readily observable by field

* As-built prints should be delivered to the organization having project management responsibility. As-built tracings should be delivered to CE&UO Engineering Files, 760 Building
inspection. (Note: Make certain that such details will be accessible after start-up. A location in a radiation zone may not be accessible at all).

(b) Wiring, tubing and piping locations when such installation are normally installed from diagramatic type drawings and when the locations are readily observable by field inspection. (See Note following a, above).

(c) Temporary features which are to be dismantled or abandoned after project completion.

Upon completion of construction, two identically marked sets of as-built drawings and specifications shall be furnished to the Commission. When tracings are to be as-built, the following should be added to the above:

"The Architect-Engineer shall, in addition, correct the original tracings to the as-built conditions as shown on the marked prints."

For further information on as-built drawings, the HAPO Design Engineer should review his Department Instruction, OPG or Advice on as-built drawings.

(3) ASME Code Vessels - Third Party Inspection

When projects involve ASME Code vessels, the supplemental criteria should include the necessary information to insure that the HAPO requirements for ASME Code compliance and third party inspection will be satisfied. These requirements are covered in HAPO OPC's.

(4) Preparation of Drawings

When applicable the following information should be furnished to the Architect-Engineer:

(a) Drawings shall be prepared on white linen tracing cloth, 8-1/2" x 11", 17" x 22", 22" x 34", or 28" x 40", with proper HAPO title block. Title block will be furnished to Architect-Engineer. The title block on each sheet shall bear the building and project number. The drawing number space in the title block is reserved for HAPO drawing numbers. Architect-Engineers shall enter HAPO-assigned drawing numbers in these spaces. Blanks for "Sheet No." should be used only when there is more than one drawing with the same number.

(b) All drawings shall be penciled, unless otherwise instructed.

(c) A drawing index shall be prepared listing all drawings by number and title.
(d) All drawings shall carry complete reference, both on the drawing proper and in the space provided near the title block for reference drawings, to all immediately related drawings, the "Next Used On" drawing number, and the drawing index."

(5) Preparation of Specifications

(a) When applicable the following should be included in supplemental criteria:

"1. Final specifications shall be prepared on masters suitable for multilith type reproduction on medium or long run masters. (Specification masters become the property of the Commission upon completion of the Architect-Engineer's contract)

2. Specifications shall be prepared for reproduction on 8-1/2" x 11" size sheets. Each specification shall have a combination title and approval sheet, and a table of contents sheet. The specification number shall appear on the approval sheet, the table of contents sheet, and on the lower right hand corner of each other page of the specification. Architect-Engineers should request specification numbers through proper channels. The page numbers shall run consecutively from the first to last sheet of the specifications and shall be placed near the bottom edge of each page near the center".

(b) An example of approval sheet and a typical specification page showing the preferred paragraph numbering system are shown in Appendix II & III.

(6) Copies of Final Design Drawings Prior to Completion

When it is required, specify that the Architect-Engineer shall submit copies of final design drawings prior to completion for checking compliance with design criteria and scope. State the number of copies of prints which must be submitted.

(7) Equipment Layout Drawings and Installation Specifications

When applicable the following requirements should be included in supplemental criteria:

"Layout and foundation drawings and installation specifications for all equipment shall be prepared. For complex installations, layout drawings shall be separate from building construction drawings and shall be used for equipment layout purposes only. They shall be accurately drawn with all equipment pieces located by dimension and by the Equipment Piece Numbers (EPN) when numbers are assigned."
(8) Drawing Schedule

When it is desired that the Architect-Engineer furnish a drawing schedule, this must be stated in supplemental criteria. If a particular form is desired, copies of the form should be provided to the Architect-Engineer.

(9) Use of Hanford Standards

Copies of those Hanford Standards and using department Engineering Standards which will be used or referenced by an Architect-Engineer should be attached to the supplemental criteria. Except for large projects, a complete set of Hanford Standards should not be sent.

(10) Identification of Equipment

When applicable, the Architect-Engineer should be required to set forth in the specifications the following as the Contractor's responsibility:

"Each piece of equipment, mechanical or otherwise, which is identified in the construction or equipment specifications by Equipment Piece Number (EPN) shall be plainly marked by the manufacturer with that number. Wherever possible, the number shall be stencilled on the item in numerals not less than 1" high using oil base paint. Where stencilling is impracticable, the number shall be stamped on a metal tag securely fastened to the item (not cemented or glued). In all cases the letters EPN shall precede the numerals".

When Equipment Piece Numbers are required for work done by an Architect-Engineer, a block of these numbers should be assigned to the Architect-Engineer.

(11) Other Items

Other items which may be required from an Architect-Engineer are:

(a) A construction cost estimate including labor cost.
(b) Manpower schedules
(c) Construction schedules
5. **SHOP DRAWINGS, MAINTENANCE INSTRUCTIONS, ETC.**

When shop drawings are required, the following should be included in supplemental criteria:

a. The Architect-Engineer shall state in the specifications what shop drawings are required to be furnished by the Contractor, in accordance with the following. Only such drawings and information as are necessary shall be required to be furnished.

(1) Approval Data

"The Contractor shall submit for review and comment or approval, (*) copies or one set of reproducibles of (fabrication and shop drawings), (circuit diagrams), (operating instructions), (parts lists), (maintenance instructions), (lubrication instructions), (performance data), (installation instructions), and all data pertinent to all structures, parts, and equipment furnished. All shop drawings must be reviewed and commented on or approved before construction is started."**

(2) Certified Data

After review and comment or approval, one set of white linen reproducibles, in sizes 8½" x 11", 17" x 22", 22" x 3½" or 28" x 40", of the fabrication and shop drawings and (*) sets of certified copies of bulletins and data sheets of the above information incorporating the results of the review, shall be furnished for each equipment item or structure. Each set of bulletins and data sheets shall be furnished in individual paper envelopes approximately 9 x 12 inches. The following information shall be prominently displayed on each envelope:

- Project No.
- Project Title
- Contract No.
- Equipment Piece No.
- Name of Equipment
- Purchaser's Name
- Order No.

* Specify required number.

** This requirement will depend on the individual project. In cases where this requirement would delay construction, it should be modified. On AEC-managed contracts, shop drawings should be submitted through the Commission for transmittal to Design Engineer for review and comment or approval.
b. Approved tracings and reproducibles and two copies of all certified data and information received at HAPO should be routed to Engineering Files, 760 Building, for filing.

6. APPROVAL OF VENDOR AND CONTRACTOR DRAWINGS

a. Approvals should be limited to those items important enough to justify the time required for an engineering review.

b. Approval of contractor or vendor drawings by the Architect-Engineer or by General Electric Co. personnel shall be made only with the approved legal terminology as follows:

"Approved - With regard to general design criteria and controlling dimensions, except as noted. This review has been a limited one, and has been made on condition that the foregoing approval by (Name of Architect-Engineer) (General Electric Company)* is based upon reliance on the (Contractor's) (Seller's)* skill and judgement. This does not constitute acceptance of any designs, materials or equipment which would not fulfill all the specifications and requirements of the (order) (contract)*".

7. ORDERING OF EQUIPMENT AND MATERIALS

a. Whoever orders equipment for a project, whether it be the HAPO Engineer, the Architect-Engineer, or the Contractor should, at the same time, order the necessary operational and construction spare parts and spare capital equipment (hereinafter referred to as "spares") for the facility.

b. The requirements for operational "spares" are to be based on written authorizations from the designated component in the using department as to items and quantities.

c. The requirements for construction "spares" are to be considered completely separate from the operational "spares" even though they are to be procured at the same time. The designation of items and quantities for construction "spares" shall be the responsibility of the HAPO Design Engineer, the organization having project management responsibility or the Architect-Engineer. If the Architect-Engineer is to be responsible, this must be specified in supplemental criteria. The HAPO Design Engineer should, in any event, follow up to see that construction "spares" are considered and ordered when necessary.

d. The information furnished for operational and construction "spares" shall be included in the bid assembly. The cost of operational and construction "spares" shall be included in the bid price and properly considered in awarding the contract.

* Whichever is applicable
The cost of construction "spares" should be included in project proposals. Funds for operational "spares" should be provided at the time the order is placed. Ordering and purchasing of construction and operational "spares" should be coordinated for maximum economy.

The above requirements should be given to an Architect-Engineer when either the A-E or the contractor will be ordering equipment.

When it is desired to have the Architect-Engineer prepare purchase specifications for advance ordering of critical equipment and materials or engineered equipment, the following or a similar write-up should be included in supplemental criteria:

"Architect-Engineer shall prepare purchase specifications for material and equipment (a) for which HAPO drawings, specifications, or data sheets, other than the purchase requisition, are required for procurement (engineered equipment) or (b) that cannot be procured in a timely and economical manner by the Contractor (critical equipment). Purchase specifications for critical items should be prepared as soon as the design is established, regardless of the completion status of the drawings and specifications. Prior to the production of purchase specifications, the Architect-Engineer shall submit for approval a schedule of critical and engineered equipment showing estimated required dates for placing orders for each item."

RELATIONSHIP WITH ARCHITECT-ENGINEER

Contractual matters are handled by the AEC. Engineers should be careful not to propose changes to the Architect-Engineer which may result in additional costs on the contract. Any dealings concerning matters bordering on changes to the Architect-Engineer contract should first be discussed with and later conducted in the presence of the AEC representatives.

ASSIGNMENT OF SPECIFICATION AND DRAWING NUMBERS, EQUIPMENT PIECE NO's, ETC

HAPO numbers for Drawings, Specifications, ATP's and Buildings or Utilities, including wells, cribs, etc., should be obtained from CE&UO Engineering Files by the responsible HAPO Engineer and furnished, when required, to the Architect-Engineer through the Commission.

CE&UO Engineering Files, 760 Building, also has custodial responsibility for all originals of HAPO drawings, specifications and ATP's. These originals should be forwarded to them for reproduction, distribution and filing.
b. The Subject File Index Numbers, also assigned by CE&UO Engineering Files, should be obtained and applied by HAPO Design Engineers to all drawings prepared at HAPO. For drawings prepared by Architect-Engineers, these index numbers should be obtained by the responsible HAPO Engineer and furnished to the Architect-Engineer.

c. When assigning Equipment Piece numbers, the Design Engineer should work closely with the operating component to assure that the numbers chosen will be of maximum benefit to the operating component, such as for spare parts identification purposes.


APMIDIX

(SAMPLE ACCEPTANCE TEST PROCEDURE APPROVAL SHEET)

GENERAL ELECTRIC COMPANY
LANFORD ATOMIC PRODUCTS OPERATION
RICHLAND, WASHINGTON

ACCETPANCE TEST PROCEDURE NO.             REV. NO.             DATE

PROJECT

SUBJECT

BUILDING

DATE PREPARED

PREPARED BY

Name

Organization

TEST PROCEDURE APPROVED

Architect-Engineer (Title II)  Date

HAPO Project Engineering (Using Dept.)  Date

HAPO Using Department  Date

Atomic Energy Commission  Date

TEST PERFORMED BY

Construction Contractor  Date

TEST WITNESSED BY

*Architect-Engineer (Title III)  Date

HAPO Project Engineering (Using Dept.)  Date

HAPO Using Department  Date

Atomic Energy Commission  Date

FINAL APPROVAL AND ACCEPTANCE

Architect-Engineer (Title III)  Date

HAPO Project Engineering (Using Dept.)  Date

HAPO Using Department  Date

Atomic Energy Commission  Date

* Design Engineering (CE&UO) to witness and approve for certain acceptance tests on process facilities.

This sample Acceptance Test Procedure approval sheet is a guide to be modified as required to fit conditions.
**APPENDIX II**

(SAMPLE SPECIFICATION APPROVAL SHEET)

*(Supplement, if such is the case) No. to

HWS

SPECIFICATIONS

FOR

(Title, include bldg no. where applicable)

Project No.)

(Original Issue Date)

(Rev no. & date or supplement date, if such is the case)

Prepared by General Electric Company

(Name of Component Preparing Specification)

Prepared by

Checked by

Approved for General Electric

(Name of Design Component) Date

(Name of Project Management Component) Date

(Name of Customer Component) Date

GENERAL ELECTRIC

HANFORD ATOMIC PRODUCTS OPERATION

*Use only for revisions or supplements. For revised issues or supplements, include original issue date.

-13-  DG-700-D
APPENDIX III
(SAMPLE SPECIFICATION SHEET)

7. TEST COUPON

a. A coupon from which specimens will be taken for each of the tests covered in Section 8 "CORROSION TESTS," shall be furnished.

b. One coupon shall be removed by as follows:
   (1) Specimen shall weigh four pounds
   (2) Specimen shall be in length.

8. CORROSION TESTS

8.1 GENERAL

Specimens taken in accordance with Section 7 "TEST COUPON" will be subjected to electrolytic oxalic acid etching test and/or a boiling nitric acid test as outlined in the following. Both tests will be performed by a laboratory designated by the purchaser and at his expense in accordance with the recommendations of ASTM A262-55T, "Tentative Recommended Practice for Boiling Nitric Acid Test for Corrosion-Resisting Steels," as supplemented by Hanford Standard HWS-8068-S, "Specification for Corrosion Testing of Stainless Steels."

8.2 ELECTROLYTIC OXALIC ACID ETCHING TEST

The electrolytic oxalic acid etching test will be used to determine the acceptability of type 304L material. When corrosion testing of type 304 material is required by the purchase order, it also will be subjected to this test. Material qualified by the etching test will be accepted; that which fails the test will be subjected to the boiling nitric acid test.

8.3 BOILING NITRIC ACID TEST

a. The boiling nitric acid test will be used to determine the acceptability of types 309SCb and 347, and of material which fails the etching test.

b. Material which passes the etching test will be accepted if:
   (1) The specimen shows no intergranular attack under a 10x glass.
   (2) The specimen shows no evidence of preferential attack.
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