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FEDERAL STANDARD

STEEL: CHEMICAL COMPOSITION AND HARDENABILITY

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STEEL: CHEMICAL COMPOSITION AND HARDENABILITY

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S3. New and revised pages will be issued under change notices which will be numbered consecutively and will bear the date of issuance. Change notices should be retained and filed in front of the standard until such time as they are superseded by a reissue of the entire standard.

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CONTENTS

FEDERAL STANDARD

STEEL: CHEMICAL COMPOSITION AND HARDENABILITY

1. SCOPE

This standard, as referenced in the applicable product specifications in procurement documents, contains:

(a) A catalog of the standard carbon steels, alloy steels (including H-steels), and stainless and heat-resisting steels that are designated by chemical composition, or (for H-steels) by chemical composition and hardenability limits by reference to standard industry documents.

(b) Rules for designating the chemical content of carbon steels, alloy steels, and stainless and heat-resisting steels that are not classified as standard.

2. CLASSIFICATION AND DESIGNATION OF STEELS BY CHEMICAL COMPOSITION

2.1 Classification. Chemical composition indicates only one aspect of a steel product and is not to be considered as a complete guide to quality and performance. Chemical composition, however, is the most common basis for the classification and designation of steels. The precise chemical content, together with the desired form (bar, sheet, strip, plate, etc.) and the size (primarily cross-sectional area or diameter, will determine whether a given product can be obtained simply by ordering a standard steel, or whether all the requirements must be specified in detail.

2.2 Standard steels. Standard steels have specified compositions and are limited to particular forms and sizes. These steels have individual numerical designations assigned by industry to facilitate ordering, as shown in table 1. The numbers are for identification and are not indicative of quality. The steel numbers used in this standard are generally Unified Numbering System (UNS) numbers; corresponding American Iron and Steel Institute (AISI) numbers and Society of Automotive Engineers (SAE) numbers are included for further information.

In general, standard steels are used more often and are more readily available than other compositions.

2.3 Former standard steels. These steels were formerly listed as "standard steels" in previous editions of this standard and the AISI manuals but, because of decreased usage, they have been placed in separate tables in the referenced documents.

2.4 Nonstandard steels. Nonstandard steels are steels which do not fall into the category of standard steels because of differences in their composition. These unlisted steels must be ordered by specifying the chemical content in accordance with established ranges and limits.

2.5 H-steels. A number of alloy steels, identified by the prefix or suffix letter "H" to the steel number, may be designated by a combination of hardenability and composition. The hardenability data compiled for each of these steels, have been derived from extensive standard (Jominy) endquench hardenability testing, and have been incorporated into composite graphs. Each graph has two curves, plotted from the maximum and minimum hardness values reported for 1/16-inch distances from the quenched end of a standard one-inch diameter specimen. The band created by these two curves defines the hardness limits for that composition. Hardenability bands and directions for their use in specifying H-steels are explained in 7.2.

2.5.1 Chemical composition limits. The chemical composition limits of the H-steels have been modified somewhat from the ranges or limits applicable to the same grades when specified by chemical composition only so that steel producers will be able to meet a common standard of hardenability limits. The modifications permit adjustments in manufacturing range of chemical composition to correct for individual plant melting characteristics which might otherwise influence the levels and widths of the hardenability bands. The modifications are not great enough to influence the general characteristics of the original compositions of the series under consideration.

3. VERIFICATION OF CHEMICAL COMPOSITION

3.1 Definitions.

3.1.1 Cast or heat analysis. Cast or heat analysis is the determination of the chemical composition of a melt, blow, or heat of steel as represented by samples obtained from the first part or middle part of the heat during pouring of the steel from a ladle. This analysis is representative of the product of a heat of steel as delivered and as reported to the purchaser.

3.1.2 Product analysis. Product analysis is a chemical analysis of steel in the semifinished or finished product form. The steel can be subjected to product analysis by the purchaser either for the purpose of verifying that the chemical composition is within specified limits for each element, including applicable tolerance for product analysis, or to determine variation in composition within a heat or lot; it is not used to confirm previous results. The results of analyses representing different locations in the same piece or taken from different pieces of a heat or lot may differ, within permissible limits, from each other and from the cast or heat analysis.

3.1.3 A "melt" of steel is the metallic output of one charge of an electric furnace.

3.1.4 A "heat" is the metallic output of one furnace charge in the open hearth or the basic oxygen process.

3.1.4 A "blow" is the metallic output of one furnace charge in the bessemer process.

3.2 Sampling for cast or heat analysis. Unless otherwise specified in the contract or order, sampling procedures for cast or heat analysis will be in accordance with standard industry practice. Usually, at least three samples are taken representing the first, middle, and last portions of the heat. Drillings taken from the first sample or middle sample are used in determining cast or heat analysis. The additional samples are used for survey of uniformity and for control purposes.

3.3 Reporting cast or heat analysis. The chemical composition specified for cast or heat analysis is shown by percentages of the elements, expressed as minimum or maximum limits or as ranges. With the exception of phosphorus and sulfur, all elements are reported to two decimals. Phosphorus and sulfur, up to 0.060 percent inclusive, are usually reported to three decimals; above 0.060 percent they are usually reported to two decimals. Values are normally rounded off to the nearest hundredth percent.

3.4 Sampling for product analysis. In sampling for product analysis, each heat of steel in a lot is considered separately unless otherwise specified. The number of samples selected for analysis is usually indicated by the applicable product specification. Because of segregation, the location at which samples for product analysis are obtained is important. Product analysis must be performed on steel in the condition received from the producer because steel subjected to subsequent heating operations may not yield analytical results that correctly represent the original composition. The detailed procedures for obtaining product analysis chips or drillings (samples) for various forms and sizes of the product are shown in table 2.

3.5 Tolerances for product analysis. Individual determinations may vary from the specified limits or ranges to the extent shown in the applicable product analysis tables, but the several determinations of any element in a heat may not vary both above and below the specified range.

Because of a characteristic lack of uniformity, no product analysis is ordinarily required for carbon, phosphorus, and sulfur in rimmed or capped steels, nor for phosphorus and sulfur in rephosphorized or resulphurized steels, unless misapplication (error in identification) is clearly indicated.

4. CARBON STEEL COMPOSITIONS

4.1 Description. The chemical composition, ranges and limits, and product analysis tolerances for carbon steels are covered in tables contained in the Steel Products Manual published by the American Iron and Steel Institute (AISI). The applicable sections of the Manual, covering the available forms, are as follows:

(a) Carbon Steel Strip

(b) Carbon Sheet Steel (Coils and Cut Lengths)

(c) Wire and Rods, Carbon Steel

(d) Carbon Steel: Plates; Structural Shapes; Rolled Floor Plates; Steel Sheet Piling

(e) Carbon Steel: Semifinished for Forging; Hot Rolled and Cold Finished Bars; Hot Rolled Deformed Concrete Reinforcing Bars

(f) Steel Specialty Tubular Products

4.1.1 Bars, semifinished products, wire rods, wire, and seamless tubing. Standard carbon steels are available as bars, and as semifinished products (blooms, billets, and slabs) for forging. Standard carbon steels are also available as wire rods, wire, and seamless tubing. In addition, a small number of carbon steels have been developed exclusively for both seamless and welded tubing.

4.1.2 Plates, sheet, strip, structural shapes, and welded tubing. Chemical composition for carbon steel plates, sheet, strip, structural shapes, and welded tubing are ordered by one of two methods:

(a) The steel may be designated as one of the standard SAE nonresulphurized carbon steels developed exclusively for these forms.

(b) The chemical content may be ordered in accordance with applicable AISI ranges and limits.

The standard SAE nonresulphurized carbon steels for plates, sheet, strip, shapes, and welded tubing are identified by the same four-digit numbers used to identify the standard AISI-SAE steels for bars, semifinished products, wire rods, wire, and seamless tubing. However, comparable compositions from both groups are not identical despite identification numbers; they differ in the range of content shown for particular elements (usually carbon). Therefore, in ordering, specify the identification number, the form desired (sheet, strip, etc.), and the prefix designation "SAE".

Table 1. Numerical designation of steels by composition

Classification	Groupings	Series designation		
		UNS	AISI	SAE
Carbon steels	Plain (nonresul.)			
	Low carbon	Up to G10130	Up to 1013	Up to 1013
	Med. low carbon	G10130 to G10220, incl.	1013 to 1022, incl.	1013 to 1022, incl.
	Med. high carbon	Over G10220 to G10410, incl.	Over 1022 to 1041, incl.	Over 1022 to 1041, incl.
	High carbon	Over G10410	Over 1041	Over 1041
	High manganese	G15240 to G15520, incl.	1524 to 1552, incl.	1524 to 1552, incl.
	Free-cutting (free-machining)			
	Resulphurized	—	11xx	11xx
	Rephosphorized and resulphurized	—	12xx	11xx
Alloy steels	Manganese	G13xxx	13xx	13xx
	Boron	—	14xx	14xx
	Nickel-chromium	—	31xx	31xx
		—	33xx	33xx
	Molybdenum	G40xxx	40xx	40xx
		G44xxx	44xx	44xx
		—	45xx	45xx
	Chromium-molybdenum	G41xxx	41xx	41xx
	Nickel-chromium-molybdenum	G43xxx	43xx	43xx
		G47xxx	47xx	47xx
		G81xxx	81xx	81xx
		G86xxx	86xx	86xx
		G87xxx	87xx	87xx
		G88xxx	88xx	88xx
		—	93xx	93xx
		—	98xx	98xx
	Nickel-molybdenum	G46xxx	46xx	46xx
		G48xxx	48xx	48xx
	Chromium			
	Low	G501xx	50xx	50xx
		G51xxx	51xx	51xx
	Low (bearing)	—	50xxx	501xx
	Medium (bearing)	—	51xxx	511xx
	High (bearing)	—	52xxx	521xx
	Chromium-vanadium	G61xxx	61xx	61xx
	Silicon-manganese	G92xxx	92xx	92xx
	Boron intensified	G50xxx to G50xxx, incl.	xxBxx	xxBxx
	Leaded	—	xxLxx	xxLxx
Stainless and heat-resisting steels	Austenitic (nonhardenable)			
	Chromium-nickel-manganese	S201xx, S202xx, S205xx	2xx	202xx
	Chromium-nickel	S3xxxx (certain designations only)	3xx	303xx
	Martensitic (hardenable chromium)	S4xxxx (certain designations only)	4xx	514xx
	Ferritic (nonhardenable chromium)	S4xxxx (certain designations only)	4xx	514xx
	Special heat-resisting (low chromium)	S50xxx	5xx	515xx

Table 2. Procedures for obtaining product analysis samples

Form	Size characteristics	Cross-sectional area, sq. in. (sq. cm.)	Drill diameter, in. (mm) (approx.)	Sampling instructions[a]
Bars, rounds squares, hexagons, shapes	Small sections	Not over 0.75 (4.84)	---	Chips shall be taken by milling or machining the full cross section of the piece.[b]
Bar-sized shapes; light flat bars	Width of cross section greatly exceeds thickness	All	1/2 (12.7)	Chips shall be taken by milling or machining the full cross section or by drilling through the steel at a point midway between the outside and center as shown in A, figure 1.[b]
Blooms, billets, slabs, rounds, squares, shapes	Large sections	Over 0.75 (4.84) to 16.0 (103.2)	1/2 (12.7)	Chips shall be taken at any point midway between the outside and center of the piece by drilling parallel to the axis. If impracticable, the piece may be drilled on the side as shown in B and C, figure 1, provided chips are not taken until they represent the portion midway between the outside and center.[b]
		Over 16.0 (103.2)	1 (25.4)	
Bored forgings	---	To 16.0 (103.2)	1/2 (12.7)	Samples from bored forgings shall be taken midway between the inner and outer surface of the wall.
		Over 16.0 (103.2)	1 (25.4)	
Plates	Thickness up to 2 inches (50.8mm)	---	1/2 (12.7)	Chips shall be taken by drilling through the thickness of the plate.[b]
	Thickness 2 inches and over (50.8mm)	---	1/2 (12.7)	Chips shall be taken by drilling the edge of the plate at a point midway between the rolled surface and the midthickness.[b]
		---	1 (25.4)	
Sheet, strip	Not of the full size rolled (cut) from larger sheets)	---	1/2 (12.7)	Chips shall be taken by milling or drilling entirely through the steel in a sufficient number of pieces so that the chips are representative of the entire sheet or strip.[b] Sheet or strip may be folded both ways to facilitate sampling.
		---	1 (25.4)	
Sheet, strip	Rolled longitudinally	---	1/2 (12.7)	Specimen for sampling shall be cut 2 inches (50.8mm) in width and across full width as rolled.
			1 (25.4)	Specimen shall be cleaned and then folded once or more by bringing ends together and closing bend. Chips shall be taken in middle of length by milling inside sheared edges or by drilling entirely through from the flat surface. (Milling preferred.) Several light-gage pieces may be stacked together for folding simultaneously.
Sheet, strip	Rolled transversely	---	1 (25.4)	Specimen shall be cut from side of as-rolled piece, halfway between the middle and end, and shall be 2 inches (50.8mm) in width and 18 inches (457.2mm) in length. Remainder of procedure is the same as for sheet and strip rolled longitudinally.
Sheet	Rolled transversely; 0.036-inch (0.914mm) or less	---	1/2 (12.7)	Specimen shall be cut from full length of sheet as rolled. Remainder of procedure is the same as for sheet and strip rolled longitudinally.
		---	1 (25.4)	
Tubular products	---	To 16.0 (103.2)	1/2 (12.7)	Drillings shall be taken from several points of each tube sampled as practicable.[b] Chips shall be taken by milling or machining full cross section.
		Over 16.0 (103.2)	1 (25.4)	
Wire rods and wire	---	---	---	Chips shall be taken by milling or machining the full cross section of the wire or wire rod.

[a] Each sample shall consist of not less than 2 ounces (56.7 grams) of drillings, unless otherwise specified. Drillings or chips shall be taken without the application of water, oil, or other lubricant, and all chips or drillings shall be free from scale, grease, dirt, or other foreign substances. Chips or drillings shall not be overheated during cutting. Chips shall be well mixed, and shall pass an ASTM No. 10 (2000 microns) sieve and shall be retained on an ASTM No. 30 (590 microns) sieve.

[b] When steel is subject to tension tests, drillings for product analysis may be taken from a tension test specimen or from the steel at the location of the tensile specimen, provided the specimen corresponds to the applicable sampling conditions.

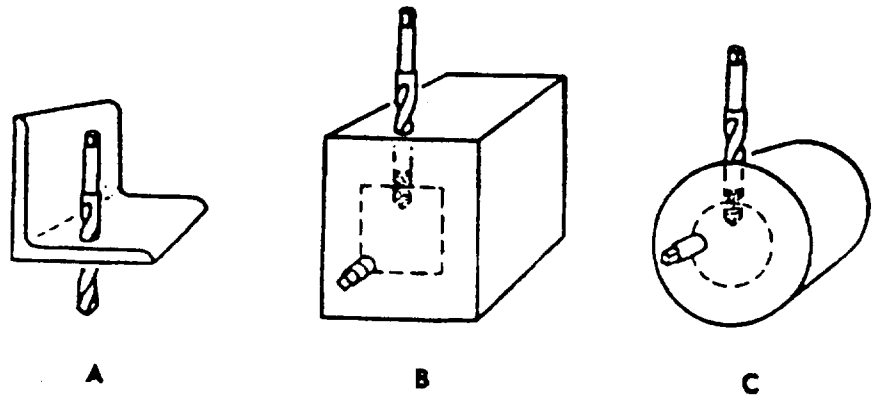


FIGURE 1. Drill locations for obtaining product analysis samples.

5. STAINLESS AND HEAT-RESISTING STEEL COMPOSITIONS

5.1 Forms. Stainless and heat-resisting steels specified by composition are ordered as standard steels and are available as bars, as semifinished products (blooms, billets, and slabs) 4 inches square or larger, and as plates, shapes, sheet, strip, and wire.

5.2 Description. The chemical composition and product analysis tolerances for stainless and heat-resisting steels are covered in tables contained in the Steel Products Manual published by AISI. The applicable section of the Manual is titled Stainless and Heat Resisting Steels.

6. ALLOY STEEL COMPOSITIONS

6.1 Forms. Standard alloy steels, ordered by identification number, are available as bars, billets, blooms, and slabs. They are generally also available as shapes, sheet, strip, wire, and seamless tubing. Some producers may not furnish standard alloy steels in all of these forms, or they may accept orders only if based on specifying such forms as "other-than-standard" steels.

6.2 Description. The chemical composition, ranges and limits, and product analysis tolerances for alloy steels are covered in tables contained in the Steel Products Manual published by AISI. The applicable sections of the Manual, covering the available forms, are as follows:

(a) Alloy Steel Sheets and Strip

(b) Wire and Rods, Alloy Steel

6.3 Unlisted alloy steels. Unlisted alloy steels include:

(a) Semifinished products (blooms, billets, and slabs) that exceed 200 square inches in cross-sectional area.

(b) Basic forms (bars, semifinished products, plates, shapes, sheet, strip, wire, and seamless tubing) ordered in compositions that are not standard, i.e. the percentages of some of the elements are outside of the chemical composition ranges shown in the tables for standard alloy steels.

7. STANDARD H-STEELS

7.1 Identification. H-steels are comprised of standard steels manufactured to fine-grain steel practices and available as bars, billets, blooms, and slabs, or seamless tubing. These steels are ordered by identification numbers including the prefix or suffix letter "H" as well as by hardenability limits selected in accordance with 7.2. Chemical composition for other sizes and forms, as well as hardenability limits for coarse-grain steels must be negotiated between the procuring agency and the contractor. The chemical compositions of standard H-steels are covered in Volume 1 of the SAE Handbook published by the Society of Automotive Engineers (SAE) and in the following sections of the Steel Products Manual published by AISI:

(a) Wire and Rod, Alloy Steel

(b) Alloy Steel: Semifinished; Hot Rolled and Cold Finished Bars

7.2 Hardenability bands. Typical hardenability band limits are shown graphically and as tabulations in Figure 2. In graphic form, the horizontal coordinate represents the distance from the quenched end of the standard (Jominy one-inch, end-quench hardenability) test bar, while the vertical coordinate represents the Rockwell "C" hardness values derived from the test data. In tabular form, one column represents the distance away from the quenched end of the standard test bar, while two other columns indicate the minimum and maximum Rockwell "C" hardness values for each distance.

Hardenability band limits for all H-steels are contained in Volume 1 of the SAE Handbook published by SAE and in the following sections of the Steel Products Manual published by AISI:

(a) Wire and Rod, Alloy Steel

(b) Alloy Steel: Semifinished; Hot Rolled and Cold Finished Bars.

The graphs are used for estimating the hardness values obtainable at various depths, and also for comparing hardenability. To ensure accuracy and uniformity, the tabular values are used for specifying hardenability limits.

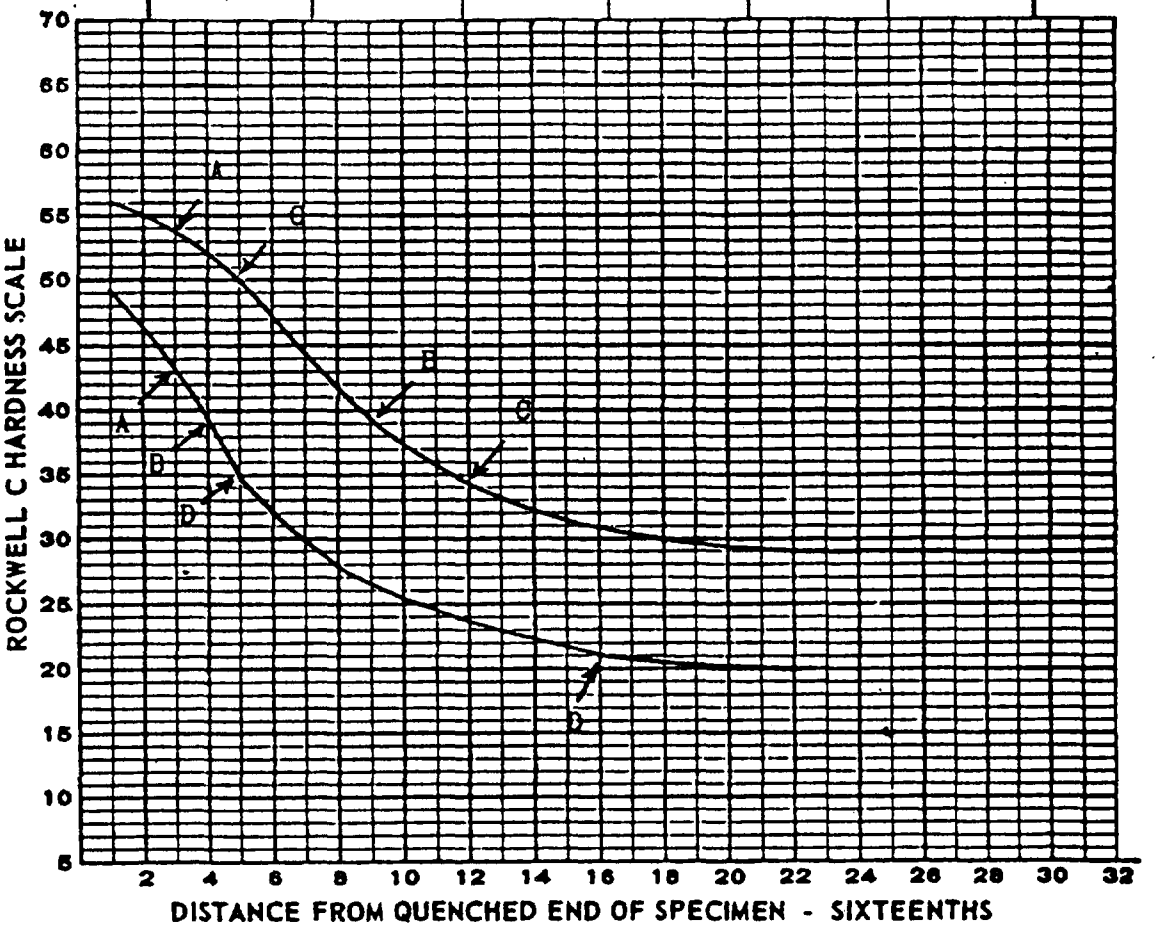
Hardenability limits are specified as a range; hence two or more values are selected to designate the desired hardenability. The preferable method is to designate only two values from the hardenability table. There are four methods of designating the two values, depending on known design requirements. Figure 2 illustrates each of the four methods of designating hardenability.

In cases where it is necessary to specify more than two points on the hardenability band (exclusive of the maximum and minimum limits at a distance of 1/16 in.), a tolerance of two points Rockwell "C" over any small portion of either curve (except at a distance of 1/16 in.) is customary. This tolerance is necessary because curves of individual heats vary somethat in shape from the standard band limits and thus deviate slightly at one or more positions in the full length of the curves. This method, however, may result in procurement difficulties and higher costs because of the additional problems in producing heats of H-steel so that all hardness values will fall within the standard band.

When an H-steel is specified, the contractor will report to the procuring agency the hardenability characteristics of each heat of steel supplied. The hardenability will be shown by hardness values at the specified reference points. However, if the full H-band is specified, hardness values will be shown at the following distances from the quenched end of a standard test specimen: 1/16, 1/8, 1/4, 1/2, 3/4, 1, 1-1/4, 1-1/2, 1-3/4, and 2 inches. Values below 20 Rockwell "C" are not specified because such values are below the normal range of the "C" scale. The hardenability will be determined from either a cast, rolled, or forged bar tested in accordance with the end-quench hardenability test described in ASTM A255, End-Quench Test for Hardenability of Steel.

HARDENABILITY BAND H86300

C	Mn	Si	Ni	Cr	Mo
.27/33	.60/.95	.20/.35	.35/.75	.35/.65	.15/.25



Method	Example
A—Minimum and maximum hardness values at a desired distance.	A-A—J43/54 = 3/16 in.
B—A desired hardness value at minimum and maximum distances.	B-B—J39 = 1/16 in. to 5/16 in. (Minimum distance to nearest 1/16 in. at left and maximum to nearest 1/16 in. at right).
C—Two maximum hardness values at two desired distances.	C-C—J50 = 3/16 in. max. J34 = 13/16 in. max.
D—Two minimum hardness values at two desired distances.	D-D—J35 = 1/16 in. min. J21 = 15/16 in. min.

FIGURE 2. Examples illustrating alternate methods of specifying requirements. (Tabulated hardness values used in ordering).

MILITARY CUSTODIANS:

Army - MR
Navy - SH
Air Force - 11

Review activities:

Army - MI, MR
Navy - AS, YD
DSA - IS

User activities:

Army - AT, AR, ME
Navy - SA

Preparing activity:

Army - MR

CIVIL AGENCIES INTEREST:

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FSS
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