SECTION 11—MATERIALS TECHNOLOGY

OVERVIEW

Many classes of materials inherently have both military and commercial applications. While commercial applications are generally at lower performance levels than those of the military, this is not always the case. This section identifies those materials that provide specific military advantage and covers the physical properties, mechanical properties, behavior, and/or processing required to achieve that advantage. The technologies include materials engineered to defeat an enemy threat and functional materials needed to preserve the capability of high-performance hardware in daily operations. This section addresses seven categories of materials technology: The six listed above plus **Biomaterials**. **The Biomaterials** category addresses materials that function in biological application (e.g., medical implants) or are derived through biological types of processes (e.g., spider silk). This category is the subject of much R&D interest, but no militarily critical applications have been identified to date. Consequently, this category will not be discussed further in this volume. Armor materials include those materials and material systems specifically designed to protect equipment and personnel from enemy threats. **Anti-Armor** materials include those materials for projectiles used to defeat enemy armor. Materials for various types of penetrators, sabots, shaped charge liners, and their launchers are included. Because of the close interaction between the design of armor systems to protect against a threat and the design of systems to defeat armor, both the subcategories of materials technology are addressed under the combined **Armor and Anti-Armor materials** technology area. Superconducting electrical materials that provide the capability for lightweight, compact, high-power motors, magnets, and energy storage systems are addressed under **Electrical Materials**. Similarly, **Magnetic Materials** addresses a few specific materials with military applications in magnetic shielding, sonar, and high-speed power supplies. Materials critical to the reliable transmission of electromagnetic radiation to surveillance sensors, weapon guidance systems, or for countermeasures purposes while protecting the associated electronic componentry from the environment are addressed under the **Optical Materials** category. **Structural Materials** addresses a broad range of materials classes used for the fabrication of military systems. This category is subdivided into (1) high-strength materials, which encompass those materials used for fabrication of military vehicles of virtually every shape and description and (2) high-temperature materials, which are used primarily for propulsion purposes and hypersonic airframes. Those materials such as high-temperature lubricants, hydraulic fluids, anti-fouling coatings required for U.S. military hardware to operate reliably at superior levels of performance are addressed under the heading of **Special Function Materials**. Materials, systems, and arrangements used for **Signature Control** are addressed in Section 16.

SECTION 11.1—ARMOR AND ANTI-ARMOR MATERIALS

OVERVIEW

This subsection covers armor materials which includes metals and related composites, ceramics and related composites, and organic fibers and composites. Of special interest are ceramics that are near theoretical (> 98 percent) density, e.g., titanium diboride, boron carbide, and aluminum oxide; composite material; arrays of metal plates; ceramics; arrays of woven cloth; ceramics and metals; ceramics or single crystal whiskers in a bonded matrix; layers of metals; and high-explosive and very dense materials. Applications include body armor and vehicle armor protection of platforms/ vehicles, satellites, and tactical shelters. Anti-armor materials include steel, titanium, ceramics, and applique arrangements. Anti-armor materials of concern include forged or explosively formed or rolled molybdenum, tantalum, tungsten, and depleted uranium (DU).

Table 11.1-1. Armor and Anti-Armor Materials Militarily Critical Technology Parameters

Technology	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Export Control Reference
Tungsten	Elongation >3% yield strength > 1250 MPa Ultimate tensile strength greater than 1270 MPa (185,900 psi) Density > 17.5 g/cm^3.	Not applicable	Manufacturing, inspection and test equipment for projectile components and subcomponents	None identified	CCL EAR 99
Copper, molybdenum or tantulum shaped charge liners	Density greater than 95% of theoretical	Not applicable	Shear/spin forming equipment capable of forming these materials to required tolerances	Programs to control forging and rolling of these materials	WA ML 16, 18, 21, 22 WA Cat 2B, D, E USML XXI, 121.10 CCL Cat 2B, D, E
Depleted uranium	In bar stock and as fabricated penetrators density greater than 18.0 gm/cm^3, Yield strength greater than 850 MPa, Ultimate tensile strength greater than 1200 MPa; elongation > 20%	Not applicable	None identified	None identified	WA ML 3, 21, 22 USML III, XXI
Silicon carbide	Density equal or greater than 98% theoretical	Not applicable	None identified	None identified	CCL EAR 99
Titanium diboride	Density equal or greater than 98% theoretical	Not applicable	None identified	None identified	WA Cat 1C, E CCL Cat 1C, E
Boron carbide	Density equal or greater than 98% theoretical	Not applicable	None identified	None identified	WA Cat 1C, E CCL Cat 1C, E

(Continued)

Table 11.1-1. Armor and Anti-Armor Materials Militarily Critical Technology Parameters (Continued)

TECHNOLOGY	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Export Control Reference
COMPOSITE MATERIALS SPECIALLY DESIGNED FOR KE ABSORPTION TO RESIST FRAGMENTATION OR TO IMPEDE SHOCK WAVE TRANSMISSION	Arrays of metal plate & low density foams or arrays of metal plates, ceramics and adhesive, or arrays of woven cloth, ceramics and metals; or Ceramics or single crystal whiskers in a bonded matrix; or Layers of metals and high explosives and very dense material, all in configurations specially designed to absorb kinetic energy, to resist fragmentation, to impede transmission of shock waves or to change the orientation of a projectile prior to penetration. Thus, each configuration is application-design specific.	Not applicable	None identified	None identified	WA ML 13, 18, 22 USML X

SECTION 11.2—ELECTRICAL MATERIALS

OVERVIEW

This subsection covers a limited group of superconducting materials in the form of wires, which permit very high field magnets and solenoids to perform at levels unattainable by other means.

Table 11.2-1. Electrical Materials Militarily Critical Technology Parameters

TECHNOLOGY	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Export Control Reference
MULTIFILAMENTARY SUPERCONDUCTIVE COMPOSITE CONDUCTORS CONTAINING NIOBIUM-TITANIUM	With lengths exceeding 100 m or with mass exceeding 100 g; and (1) Embedded in a matrix other than a copper or copper-based mixed matrix; or (2) With a cross-sectional area less than 28 square micrometers.	Nb	None identified	None identified	WA Cat 1C, E CCL Cat 1C, E
SUPERCONDUCTIVE COMPOSITE CONDUCTORS CONSISTING OF ONE OR MORE SUPERCONDUCTIVE FILAMENTS EXCLUDING NIOBIUM-TITANIUM AND CERAMIC OXIDES	With lengths exceeding 100 m or with mass exceeding 100 g; and (1) 9.85 K< T_c < 24 K at B = 0; (2) With cross-sectional area < 28 square micrometers; and (3) Which remain in superconducting state at T = 4.2 K when exposed to a magnetic field corresponding to B = 12 T or greater	Nb	None identified	None identified	WA Cat 1C, E CCL Cat 1C, E
SUPERCONDUCTIVE COMPOSITE CONDUCTORS CONSISTING OF ONE OR MORE SUPERCONDUCTIVE FILAMENTS CONTAINING CERAMIC OXIDES	With lengths exceeding 100 m and T_c > 24 K at B = 0; and which has "overall current density" of 10,000 amps/square centimeter exposed to a magnetic field corresponding to B = 2 T or greater	None identified	None identified	None identified	CCL EAR 99

SECTION 11.3—MAGNETIC MATERIALS

OVERVIEW

This subsection covers types and applications of magnetic materials that are militarily significant. These include (1) high relative permeability nickel-rich iron-nickel alloy sheets with 4 percent to 6 percent molybdenum; (2) magnetostrictive alloys, primarily rare earth iron alloys; and (3) both amorphous alloy strips and nanocrystalline alloy strips consisting of iron, cobalt, and/or nickel with boron, silicon, or phosphorous. Magnetic materials is an area where significant R&D activity is taking place in both nongovernment and government laboratories as well as abroad.

Table 11.3-1. Magnetic Materials Militarily Critical Technology Parameters

Technology	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Export Control Reference
High permeability alloys	Sheets with initial relative permeability (for fully annealed materials) of 120,000 or more;. Thickness of 0.05 mm or less; typically, but not limited to, Ni rich Fe-Ni with Mo concentrations of 4 to 6%	None identified	Hydrogen Anneal Equipment	None identified	WA Cat 1C, E CCL Cat 1C, E
Magnetostrictive alloys	With saturation magnetostriction > 500 ppm; or magnetomechanical coupling factor (k) > 0.8; primarily but not limited to rare earth alloys	None identified	None identified	None identified	WA Cat 1C, E CCL Cat 1C, E
Amorphous alloys	Strips with a composition having at least 75 weight percent Fe, Co, or Ni; and a saturation magnetic induction (Bs) of 16 kG or more; Strip thickness of 0.02 mm or less; or an electrical resistivity of 0.0002 ohm-cm or more	None identified	None identified	None identified	WA Cat 1C, E CCL Cat 1C, E
Nanocrystalline alloys	Strips with a composition having at least 75 weight percent Fe, Co or Ni; and a grain size < 50 nm saturation magnetic induction (Bs) of 16 kG or more; and, a strip thickness of 0.02 mm or less; or an electrical resistivity of 0.0002 ohm-cm or more	None identified	None identified	None identified	WA Cat 1C, E CCL Cat 1C, E

SECTION 11.4—OPTICAL MATERIALS

OVERVIEW

This subsection includes mature material technologies for linear and nonlinear optical transmission in the visible and/or IR spectral regimes, including bulk materials and thin films and coatings. Special emphasis is placed on materials and coatings that are affordable, maintainable, and durable in the harsh environments experienced in military operations, such as the high-speed exposure to rain and dust and/or high temperatures and the high structural loads associated with high-speed, maneuvering flight. This subsection includes (1) IR Optical Materials, (2) IR coating materials for protection against hazardous environments, (3) germanium optics, (4) specialty transparent materials for coatings and filters, (5) nonlinear optical (NLO) materials for wavelength conversion, and (6) substrates and optical film for high energy laser optical components (mirrors, beamsplitters, windows).

Table 11.4-1. Optical Materials Militarily Critical Technology Parameters

TECHNOLOGY	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Export Control Reference
IR OPTICAL ELEMENTS (I.E. BULK OPTICAL MATERIALS IN COMBINATION WITH APPROPRIATE COATINGS)	Transparent over any portion of the 1–12 microns spectral band and strength > 48 MPa (7 ksi), plus any of the following: plate size > 8 cm diameter, or domes of any size, or withstand 2 mm dia. raindrop impacts at 2.5 cm/hr rate at > Mach 1.0, or survive aerothermal heating rate > 100 w/cm^2	ZnS and ZnSe >100 cm^3 in volume or > 8 cm diameter with thickness > 2 cm.	Equipment for rapid polishing of IR window materials. Single point diamond turning machines	None identified	WA Cat 2B, D, E WA Cat 6C, E CCL Cat 2B, D, E CCL Cat 6C, E
IR COATING MATERIALS FOR PROTECTION AGAINST HAZARDOUS ENVIRONMENTS.	Rain and dust erosion; oxidation resistant at > 700 C; anti-reflection	Diamond-like carbon (DLC), diamond, MgO, ThF_4, BP, Ge	Equipment for measuring absolute reflectance to an accuracy of ± 0.1%.	None identified	WA Cat 2E CCL Cat 2E
GERMANIUM (Ge) OPTICS	Resistivity < 15 ohm cm Absorption □.03 cm^{-1} @ 10.6 microns; Diameter > 15 cm; Withstand blowing sand at 8 m/s wind velocity with particle density > 1.0 gm/m^3 and particle size distribution 74–350 microns	Ge	Equipment for rapid polishing of IR windows and domes	None identified	CCL EAR 99
SPECIALTY TRANSPARENT MATERIALS FOR COATINGS/FILTERS	Selectable or variable bandpass or narrow rejection in 0.2–20 micron spectral region	Selected oxides and dielectrics (application dependent)	For control of coating deposition, especially thickness and composition.	Controls for deposition of coatings/ insitu characteriza-tion of coatings.	WA Cat 2E CCL Cat 2E

(Continued)

Table 11.4-1. Optical Materials Militarily Critical Technology Parameters (Continued)

TECHNOLOGY	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Export Control Reference
NONLINEAR OPTICAL (NLO) MATERIALS FOR WAVELENGTH CONVERSION	Spectral bandpass at 2–12 microns; average output power > 2 watts	$ZnGeP_2$; KTA; GaSe; RTA $CdGeAs_2$; RTA	None identified	None identified	WA Cat 6C, E CCL Cat 6C, E
HEL OPTICAL COMPONENTS (MIRRORS, BEAMSPLITTERS, WINDOWS)	Substrates Diameter > 0.25 m for single crystal Si and SiC Low water fused silica < 100 ppm water Optical coating with total loss 200 ppm	Si, SiC low water fused silica coating materials ThF4, ZnSe, SiOZ, TiO_2, ZrO_2, Nb_2O_5, Al_2O_3	Single point diamond turning coating vacuum chambers Characterization equipment to measure absorptance and laser calorimetry), BRDF scatter reflectance	None identified	WA Cat 6A, C, D, E CCL Cat 6A, C, D, E

SECTION 11.5—STRUCTURAL MATERIALS (HIGH-STRENGTH AND HIGH-TEMPERATURE)

OVERVIEW

Structural materials technology includes development, synthesis, processing, and characterization of a wide class of monolithic alloy and composite materials, as well as specialized coatings. Because the structural materials category is so broad, it has been subdivided into (1) high-strength materials used for fabrication of platforms, vehicles, and weapons and (2) high-temperature materials used primarily for propulsion. High-strength materials are very numerous, even for military systems, and include both ferrous and nonferrous metal alloys and both metal and polymer matrix composites. Included are maraging ultrahigh strength and high-strength low alloy steels; high-strength magnesium, aluminum and titanium alloys; aluminum-lithium alloys; and magnesium-, aluminum- and polymer-matrix composites, including both matrix and reinforcement constituents. Materials suitable for use at high temperature include iron-, nickel-, and cobalt-based superalloys and advanced intermetallics; tungsten and molybdenum alloys; oxide, carbide, nitride, and boride ceramics (in monolithic and composite forms); carbon-carbon composites, "high-temperature" aluminum alloys; and high-temperature protective coatings. This technology also serves as the base for emerging system technology advances. In general, structural materials have numerous dual-use applications.

Table 11.5-1a. Structural Materials (High-Strength and High-Temperature) Militarily Critical Technology Parameters

Technology	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Export Control Reference
Thermoplastic polymeric resins for elevated temperature applications	The capability of having polymer components, seals, or composite structures or laminates that can operate at temperatures ≥ 523 °K (250 °C)	Aromatic liquid crystal polymers, polyarylene ketones, polyarylene ether ketones, polyarylene sulfides, polyarylene sulfones, polyarylene ether sulfones and other polyarylene materials	None identified	Not included	WA Cat 1C, E CCL Cat 1C, E
Fluorinated and nonfluorinated polymeric materials for the matrices of composite structures or laminates	The ability to perform at temperatures ≥ 205 °C (400 °F) in operation	Fluorinated and nonfluorinated polymers; bismaleimides; aromatic polyamide-imides; aromatic polyimides; aromatic polyetherimides	None identified	None identified	WA Cat 1C, E CCL Cat 1C, E
Resin impregnated fiber prepregs utilizing fibrous or filamentary reinforcements	Specific tensile strength ≥ 23.5 x 10^4 m and Specific modulus ≥13.87 x 10^6 m for fibers or filaments T_g > 145 °C after cure (as determined by ASTM D4065 or national equivalents)	Any fiber above AS4/T-500 and matrix T_g > 145 °C after cure	Prepregging equipment, fibers, fiber treatment, resins and combination of all of these.	Not included	WA Cat 1C, E CCL Cat 1C, E

(Continued)

Table 11.5-1a. Structural Materials (High-Strength and High-Temperature) Militarily Critical Technology Parameters (Continued)

Technology	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Export Control Reference
Fibrous or filamentary polymeric materials	Organic fibers or filaments with specific tensile strength > 3.6 GPa and tensile modulus > 130 GPa and for use above 330 C (540 F)	None identified	None identified	None identified	WA Cat 1C, E CCL Cat 1C, E
Composite materials or laminates that contain continuous carbon or inorganic fibrous or filamentary materials with a polymer matrix	Fibers with specific modulus of 13.87 x 10^6 m and specific strength of > 23.05 x 10^4 m; matrix T_g > 145 °C after cure.	Any fiber with properties indicated under militarily critical parameters	All equipment associated with the production of high performance organic matrix composite components and structures	Not included	WA Cat 1A, B, C, E CCL Cat 1A, B, C, E
Aluminum alloys (PM)	Ultimate tensile strength of > 240 MPa (35 ksi) at 200 °C, 415 MPa (60 ksi) at 25 °C, with specified powder parameters; of composition Al-Mg-X; Al-X-Mg; Al-Zm-X; Al-X-Zm; Al-Fe-X; Al-X-Fe made by powder metallurgy.	None identified	Equipment to carry out process specified in WAWG 2 Item 1.C.2.b.2. Equipment for producing and processing contamination free alloy powder.	Not included	WA Cat 1C, E CCL Cat 1C, E
Aluminum and aluminum alloy matrix composites	Stiffness > 103 GPa (15 Msi) and Fracture toughness > 297 MPa root m (18 ksi) root in.	Reinforcement fibers and protective fiber coatings	None identified	Process control software	CCL EAR 99
Titanium (burn-resistant) Such as Pratt & Whitney "alloy C" (proprietary composition), or equivalent.	A temperature that supports sustained combustion 220 °C (400 °F) higher than that of traditional structural titanium alloys	None identified	Procedures and equipment designed for contamination free processing of alloys and powders or for superplastic forming and diffusion bonding.	Not included	CCL EAR 99
Titanium-matrix composites	Tensile strength ≥ 1100 MPa (160,000 psi) Elastic modulus ≥ 172 GPa (25 Msi) and Density ≤ 4.4 x 10^3 kg/m^3 (0.16 lb/in.^{3}).	Reinforcement fibers and titanium alloy foil	Hot isostatic pressing and canning equipment.	Process control software, consolidation models, and fiber spacing procedures.	CCL EAR 99
High thermal conductivity carbon fibers	Thermal conductivity Ka ≥ 1000 watts/mC	None identified	None identified	None identified	CCL EAR 99

(Continued)

Table 11.5-1a. Structural Materials (High-Strength and High-Temperature) Militarily Critical Technology Parameters (Continued)

Technology	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Export Control Reference
Two dimensionally (2D) reinforced carbon fiber carbon matrix composites	Specific modulus exceeding 10.15 x 10^6 m; and Specific tensile strength exceeding 17.7 x 10^4 m	Fibers, including pitch, PAN, high thermal conductivity fibers, high modulus fibers	Densification, weaving, automated fabrication, process control, high temp. sensors, processing (CVD, CVI, pitch impregnation, copyrolysis).	Not included	WA Cat 1A, B, C, E CCL Cat 1A, B, C, E
Composite materials or laminates that contain continuous carbon or inorganic fibrous or filamentary materials within metal or carbon matrices	Carbon fibers with specific tensile strength > 7.7 x 10^4 m and Specific modulus > 10.15 x 10^5 m; Inorganic fibers with specific tensile modulus > 2.54 x 10^6 m and Melting/ softening/ decomposition point > 1650 °C	Any fiber with properties indicated under militarily critical parameters	Fiber production, fiber treatments, carbon and metal infiltration equipment.	Not included	WA Cat 1A, B, C, E CCL Cat 1A, B, C, E
Ultra high strength/high toughness steel	Yield strength > 1.965 GPa (285 ksi) toughness > 111 MPa root in. (100 ksi root in)	None identified	"AerMet 100," patented by Carpenter Technology Co.	None identified	CCL EAR 99
Inorganic fibers and filamentary materials	Having specific modulus > 2.54 x 10^6 m (1650 °C) and A melting or decomposition point > 1,922 K in an inert environment	None identified	Equipment for converting polymeric fibers into carbon or silicon carbide fibers; equip for chemical vapor deposition; equipment for wet spinning of refractory ceramics and equip for converting aluminum to alumina fibers	Not included	WA Cat 1C, E CCL Cat 1C, E

Table 11.5-1b. Structural Materials (High-Strength and High-Temperature) Militarily Critical Technology Parameters

TECHNOLOGY	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Export Control Reference
TITANIUM ALLOYS (MADE FROM METAL ALLOY POWDER OR PARTICULATES OR CAST OR WROUGHT)	Advanced propulsion titanium alloys; stress rupture life of 10,000 hours or longer at 450 °C at a stress of 200 MPa	Titanium alloy powder made in controlled environment from melt or mechanical alloying	Vacuum, gas or rotary atomization, splat quenching, melt spinning and comminution, mechanical alloying or plasma spray, cospray or osprey process	Not included	WA Cat 1C, E CCL Cat 1C, E
TITANIUM ALUMINIDES	Either ductility of > 0.5% elongation at 25°C or Tensile strength of > 250 MPa at 870°C and Containing >10 weight % of aluminum; in crude or semi-fabricated forms, containing at least one additional alloying element	Not applicable	Vacuum, gas or rotary atomization, splat quenching, melt spinning and comminution, mechanical alloying or plasma spray, cospray or osprey process	Not included	WA Cat 1C, E CCL Cat 1C, E
TITANIUM-ALUMINIDE MATRIX COMPOSITES	Tensile strength > 1172 MPa at 540 °C, Creep resistance > 300 h at 634 MPa at 540°C and >10,000 cycle low cycle fatigue life at 650°C and 634 MPa	Reinforcement fibers, aluminide foil and contamination-free aluminide powder	Hot isostatic pressing and canning equipment.	Process control software	CCL EAR 99
NICKEL-BASED ALLOYS MADE FROM METAL ALLOY POWDER OR PARTICULATE MATERIAL	Stress rupture life > 10,000 hours at 550 MPa (80 ksi), 650 °C, or A low cycle fatigue life of 10,000 cycles or more at 550 °C at a maximum stress of 700 MPa	Nickel alloy powder made in a controlled environment from the melt or by mechanical alloying	Vacuum, gas or rotary atomization, splat quenching, melt spinning and comminution, mechanical alloying or plasma spray, cospray or osprey process	Not included	WA Cat 1C, E CCL Cat 1C, E
BULK GRAPHITES	Bulk density of at least 17.2 g/cc measured at 15 °C and having a particle size of 100 mm or less	Not applicable	None identified	None identified	MTCR 8 USML 121.16
DEVELOPMENT OR PRODUCTION OF PYROLYTICALLY DERIVED MATERIALS	Formed on mold or mandrel from precursor gases which decompose in 1,300 to 2,900 °C temp and range at pressure of 1 mm to 150 mm	Not applicable	Specifically designed nozzles for processing	Software for development, production and use; know-how	MTCR 7 USML 121.16

(Continued)

Table 11.5-1b. Structural Materials (High-Strength and High-Temperature) Militarily Critical Technology Parameters (Continued)

Technology	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Export Control Reference
Ceramic-ceramic composite materials with matrices of silicon–, zirconium–or boron carbide or nitride, reinforced with fibers from the C, Si-N, Si-C, Si-C-O-N, Si-Al-O-N, or Si-O-N systems or matrices of aluminum oxide or aluminum nitride, reinforced with alumina fibers	Tensile strength > 105 MPa (15 ksi) at 1000 °C	Not applicable	NDE methods still in development	Not included	WA Cat 1C, E CCL Cat 1C, E
Ceramic-ceramic composite materials with a glass oxide-matrix reinforced with fibers from any of the following systems: Si-N, Si-C, Si-Al-O-N; or Si-O-N; C, or "Nicalon"	Tensile strength > 105 MPa (15 ksi) at 1000 °C	B-Mg-Al silicate (Compglas) with C or silicon carbide fibers; "Blackglass" (SiO_2 + C)	None identified	None identified	WA Cat 1C, E CCL Cat 1C, E
3 dimensionally reinforced (3D) carbon fiber-carbon matrix composites and higher levels of reinforced ("N"D) composites	Specific modulus exceeding 10.15×10^6 m; and Specific tensile strength exceeding 17.7×10^4 m	Carbon fibers and graphite fibers including pitch, PAN, and rayon. Pitch and resin matrix systems.	High pressure densification, weaving (less than 0.030"), automated fabrication, processing equipment, computed tomography, inspection capability; impregnation equipment	Process controls (i.e., weaving, densification, time, temperature, pressure) and know-how	WA Cat 1A, B, C, E CCL Cat 1A, B, C, E
Fibrous or filamentary materials for use above 540 C (1000 °F)	Specific modulus exceeding 12.7×10^6 m; and A specific tensile strength exceeding 23.5×10^4 m; Carbon fibrous or filamentary materials with a specific modulus exceeding 12.7×10^6 m; and A specific tensile strength exceeding 23.5×10^4 m	Not applicable	Ultrasonic inspection equipment	Not included	WA Cat 1C, E CCL Cat 1C, E

(Continued)

Table 11.5-1b. Structural Materials (High-Strength and High-Temperature) Militarily Critical Technology Parameters (Continued)

Technology	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Export Control Reference
Metal alloy and intermetallic alloy powder production, handling and consolidation	Powder metals with contamination levels < 3 non-metallic particles larger than 100 microns per billion metal particles	None identified	Equipment for producing and processing contamination-free alloy powdering.	Process control software	WA Cat 1C, E CCL Cat 1C, E
Single crystal metals and intermetallics	Incipient melting points above 1090 °C	Not applicable	Equipment for single crystal blade growth; NDE/NDI equipment	Not included	WA Cat 9E CCL Cat 9E
Thermal protection coatings	Temperature at metal-coating interface > 1150 °C (2100 °F)	None identified	Plasma spray, CVD, e-beam, deposition, laser ablation (see Section 10)	Not included	WA Cat 2B, D, E CCL Cat 2B, D, E

SECTION 11.6—SPECIAL FUNCTION MATERIALS

OVERVIEW

The special function materials technology area covers a broad range of materials (over 100) for equally numerous applications. Included are hydraulic fluids and seals; turbine engine lubrication fluids and seals; high-temperature solid lubricants; protective paints and coatings for corrosion resistance; antifouling coatings for ships; rain and sand erosion-resistant coatings for missile domes; electronic cooling fluids; fuel system seals and sealants; gyro floatation fluids; and fire retarding materials. This technology area is included in current DoD R&D programs and is an area of significant activity in government and nongovernment laboratories.

Table 11.6-1. Special Function Materials Militarily Critical Technology Parameters

Technology	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Export Control Reference
Chemical/ biological agent resistant coatings	Specific formulations for substrate material/agent pairs with at least 95% of the coating being saturated elastomeric polymers	None identified	None identified	None identified	WA Cat 1A, D, E USML X CCL Cat 1A, D, E
Erosion protective coatings	Resistance to rain and sand erosion coatings composed of elastomeric polymers	Polyurethanes and fluoropolymers	None identified	None identified	WA Cat 2E CCL Cat 2E
Fluorinated polymers	Elastomeric polymers containing 10% or more of combined fluorine (by weight)	None identified	Very specialized polymerization facilities, reactor vessels, or reactors with or without agitators and suitable agitators with total internal volume > 100 liters and less than 20,000 liters	None identified	WA Cat 1C, E CCL Cat 1C, E
Completely fluorinated polymers	Fluoroelastomers containing no hydrogen	None identified	Very specialized polymerization facilities and know-how required to manufacture these materials	None identified	WA Cat 1C, E CCL Cat 1C, E
Copolymers or terpolymers made from vinylidene fluoride, hexa-fluoropropylene, tetra-fluoroethylene or perfluoro-methylvinylether	Elastomeric polymers containing 10% or more of combined fluorine (by weight)	None identified	Very specialized polymerization facilities, reactor vessels, or reactors with or without agitators and suitable agitators with total internal volume > 100 liters and less than 20,000 liters	None identified	WA Cat 1C, E CCL Cat 1C, E
Chloro-fluorocarbons	No flash point; autogenous ignition temperature > 977°K (704°C) or higher; contains only chlorine, hydrogen and carbon	None identified	None identified	None identified	WA Cat 1C, E CCL Cat 1C, E

(Continued)

Table 11.6-1. Special Function Materials Militarily Critical Technology Parameters (Continued)

Technology	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Export Control Reference
Fluorinated phosphazine polymers	Elastomers containing 30% or more by weight of combined fluorine	None identified	Very specialized polymerization facilities, reactor vessels, or reactors with or without agitators and suitable agitators, with total internal volume > l00 liters and < 20,000 liters	None identified	WA Cat 1C, E CCL Cat 1C, E
Synthetic hydrocarbons	Flashpoint >477°K (204°C); pour point 239°K (–34°C) or lower; viscosity index 75 or greater; thermal stability to 616°K (343°C) or greater	None identified	None identified	None identified	WA Cat 1C, E CCL Cat 1C, E
Silahydrocarbons	Contains only silicon, hydrogen and carbon, flash point >477°K (204°C); pour point 239°K (–34°C) or lower; viscosity index 75 or greater, thermal stability to 616°K (343°C) or greater	None identified	None identified	None identified	WA Cat 1C, E CCL Cat 1C, E
Perfluoro-polyalkyl ether based lubes and greases	Viscosity of 1.0 centistoke or more at 343°C (600°F) and 20,000 centistokes or more at -51°C; Oxidatively stable at 316°C (per ASTM D4636 or national equivalent)	None identified	None identified	None identified	WA Cat 1C, E CCL Cat 1C, E
Polyol ester based lubes	4 centistokes minimum viscosity at 100°C and 20,000 centistokes maximum at –51°C; Oxidatively stable at 220°C (per ASTM 4634 or national equivalent).	None identified	None identified	None identified	CCL EAR 99
Phenylene ether based lubes and greases [pure or mixed with alkylphenylene ether(s) or thioether(s)]	Provide lubrication over -54 °C to + 2600 C (-65 °F to + 500 °F)	None identified	None identified	None identified	WA Cat 1C, E CCL Cat 1C, E
Fluorinated silicone fluids	Kinematic viscosity less than 5000 centistokes at 25°C	None identified	None identified	None identified	WA Cat 1C, E CCL Cat 1C, E
Thio ethers [pure or mixed with phenylene and/or alkylphenylene ether]	Provide lubrication over –54 °C to + 2600 C (-65 °F to + 500 °F)	None identified	None identified	None identified	WA Cat 1C, E CCL Cat 1C, E
Polythioether based sealants	Seal over broad temperature range –54 °C to 150 °C (-65°F to 300°F)	None identified	None identified	None identified	CCL EAR 99

(Continued)

Table 11.6-1. Special Function Materials Militarily Critical Technology Parameters (Continued)

TECHNOLOGY	Militarily Critical Parameters Minimum Level to Assure US Superiority	Critical Materials	Unique Test, Production, and Inspection Equipment	Unique Software and Parameters	Export Control Reference
SOLID LUBRICANT MATERIALS	Coefficient of friction 0.12 maximum; meet the adhesion criteria of ASTM D2510; outgassing mass loss 1.0% maximum; volatile condensible material 0.1% maximum, as determined per ASTM E595; or coefficient of friction of 0.25 maximum from 4 °C to 538 °C (+ 40 °F to 1,000 °F) as per ASTM D2981; oxidatively stable at 538 °C (1000 °F) minimum; load capacity of 1.25 MPa (150,000 psi) maximum as per ASTM E595	None identified	None identified	None identified	CCL EAR 99
FLUORINATED FLUIDS FOR COOLING	Completely (100%) fluorinated	None identified	None identified	None identified	WA Cat 1C, E CCL Cat 1C, E
DIBROMOTETRA-FLUOROETHANE OR POLYCHLOROTRI-FLUOROETHYLENE OR POLYBROMOTRI-FLUOROETHYLENE BASED, FULLY BROMINATED OR FULLY CHLORINATED HIGH DENSITY FLUIDS	Contains at least 85% of the named compounds and having a purity exceeding 99.8% and Containing less than 25 particles (200 micrometers or larger) per 100 ml	None identified	Specialized synthesis and handling equipment to maintain purity of the materials	None identified	WA Cat 1C, E CCL Cat 1C, E