Overview of Composites
Figures A-1 and A-2 depict the process sequences and equipment used to manufacture composite materials controlled under the MTCR. The flow begins with the precursor materials (on the left) and progresses to the controlled end products. The controlled equipment and processes are described, and the applicable MTCR items are listed below the descriptions.

Addressing the MTCR items, Fibers are oxidized at 180–300°C under controlled tension, followed by carbonization in an inert atmosphere. The equipment includes controlled temperature and pressure furnaces, tensioning rollers, and drive motors.

The controlled equipment and processes are described, and the applicable MTCR items are listed below the descriptions. Representative process examples using some of the products shown here are illustrated in Figure A-2 on the following page.

### Representative Examples of Filament and Composite Production Processes

**Conversion of Fibers**

**Process:** Fibers are oxidized at 180–300°C under controlled tension, followed by carbonization in an inert atmosphere.

**Equipment:** Controlled temperature and pressure furnaces, tensioning rollers, and drive motors.

**MTCR:** Item 6(d)(1) Equipment for converting polymeric fibers.

**Wet Spinning**

**Ceramic Filaments**

**Process:** An aluminum oxide-based slurry is drawn through a spinneret to form fibers consisting of 480–700 filaments per tow (fiber bundle).

**Equipment:** Slurry solution piping connected to spinneret, coagulation tank, and take-up rollers.

**MTCR:** Item 6(d)(3) Equipment for the wet-spinning of refractory ceramics.

**Physical Vapor Deposition (PVD)**

**Chemical Vapor Deposition (CVD)**

**Plasma Assisted Chemical Vapor Deposition (PACVD)**

**Textile, one-dimensional weaving machine.**

**SEM Photo of coated fiber**

**Ceramic Filaments**

**Treated Filaments**

**Coated Filaments**

**Prepreg Filaments**

**Untreated Fabric**

**Prepreg Operation**

**Process:** The filaments are coated with resins or sizings by immersion, followed by drying and curing.

**Equipment:** Drive motors, tensioning rollers, and temperature-controlled resin baths comprise the majority of the equipment.

**MTCR:** Item 6(e) Equipment designed or modified for special fiber surface treatment or for producing prepregs and preforms.

**Filaments are coated by passing them through gas-filled CVD or PVD chambers at temperatures near 1200°C. Gas reaction byproducts (such as SiC) are deposited on the fibers.**

**Equipment:** The equipment used for CVD, PACVD, or PVD will include a reaction chamber, controls for temperature, and gas flow.

**MTCR:** Item 6(d)(2) Equipment for the vapor deposition of elements or compounds on heated filament substances.

**Figure A-1: Representative Examples of Filament and Composite Production Processes**

**Figure A-2: Continued**
Non-MTCR-Controlled Equipment or Process

**Process:** Filaments are drawn through a resin bath and wound onto the rotating mandrel.

**Equipment:** Rotating lathe-type machines capable of winding filaments in three or more axes.

**MTCR:** Item 6(1)(a) Filament winding machines.

---

**Process:** Fabrics are treated with resin and cut into strips to make tape.

**Equipment:** Resin bath and cutting machines.

**MTCR:** Item 6(1)(e) Equipment designed or modified for special fiber surface treatment or for producing prepregs and preforms.

---

**Process:** The prepreg tape is wound on a form or mandrel.

**Equipment:** Rotary lathe-type devices similar to filament winding machines, or numerically controlled devices capable of winding tape in two or more axes.

**MTCR:** Item 6(1)(b) Tape-laying machines.

---

**Process:** The carbon fiber preform is impregnated with hydrocarbon gas at 700–2000°C via isothermal, pressure gradient, or temperature gradient methods.

**Equipment:** CVD/CVI furnaces, associated piping, valves, pressure and temperature controls.

**MTCR:** Items 7(b)(2) & 7(c)(2) CVD furnaces and nozzles for CVD furnaces.

---

**Process:** The carbon fiber preform is impregnated with hydrocarbon gas at 700–2000°C via isothermal, pressure gradient, or temperature gradient methods.

**Equipment:** Pressure chamber, pressure generator, temperature and pressure controls.

**MTCR:** Item 7(c)(1) Isostatic presses.

---

**Process:** Filaments are interlaced to form a fabric preform.

**Equipment:** Rotating table with a network of rods, fiber spools, drive motors, and lacing needles.

**MTCR:** Item 6(c) Multi-directional, multi-dimensional weaving machines.

---

**Process:** The carbon fiber preform is impregnated with hydrocarbon gas at 700–2000°C via isothermal, pressure gradient, or temperature gradient methods.

**Equipment:** Pressure chamber, pressure generator, temperature and pressure controls.

**MTCR:** Items 7(b)(2) & 7(c)(2) CVD furnaces and nozzles for CVD furnaces.

---

**Process:** Filaments are drawn through a resin bath and wound onto the rotating mandrel.

**Equipment:** Rotating lathe-type machines capable of winding filaments in three or more axes.

**MTCR:** Item 6(1)(a) Filament winding machines.

---

**Process:** Fabrics are treated with resin and cut into strips to make tape.

**Equipment:** Resin bath and cutting machines.

**MTCR:** Item 6(1)(e) Equipment designed or modified for special fiber surface treatment or for producing prepregs and preforms.

---

**Process:** The prepreg tape is wound on a form or mandrel.

**Equipment:** Rotary lathe-type devices similar to filament winding machines, or numerically controlled devices capable of winding tape in two or more axes.

**MTCR:** Item 6(1)(b) Tape-laying machines.

---

**Process:** The carbon fiber preform is impregnated with hydrocarbon gas at 700–2000°C via isothermal, pressure gradient, or temperature gradient methods.

**Equipment:** CVD/CVI furnaces, associated piping, valves, pressure and temperature controls.

**MTCR:** Items 7(b)(2) & 7(c)(2) CVD furnaces and nozzles for CVD furnaces.

---

**Process:** The carbon fiber preform is impregnated with hydrocarbon gas at 700–2000°C via isothermal, pressure gradient, or temperature gradient methods.

**Equipment:** Pressure chamber, pressure generator, temperature and pressure controls.

**MTCR:** Item 7(c)(1) Isostatic presses.

---

**Process:** Filaments are interlaced to form a fabric preform.

**Equipment:** Rotating table with a network of rods, fiber spools, drive motors, and lacing needles.

**MTCR:** Item 6(c) Multi-directional, multi-dimensional weaving machines.

---

**Process:** The carbon fiber preform is impregnated with hydrocarbon gas at 700–2000°C via isothermal, pressure gradient, or temperature gradient methods.

**Equipment:** Pressure chamber, pressure generator, temperature and pressure controls.

**MTCR:** Items 7(b)(2) & 7(c)(2) CVD furnaces and nozzles for CVD furnaces.

---

**Process:** Filaments are drawn through a resin bath and wound onto the rotating mandrel.

**Equipment:** Rotating lathe-type machines capable of winding filaments in three or more axes.

**MTCR:** Item 6(1)(a) Filament winding machines.

---

**Process:** Fabrics are treated with resin and cut into strips to make tape.

**Equipment:** Resin bath and cutting machines.

**MTCR:** Item 6(1)(e) Equipment designed or modified for special fiber surface treatment or for producing prepregs and preforms.

---

**Process:** The prepreg tape is wound on a form or mandrel.

**Equipment:** Rotary lathe-type devices similar to filament winding machines, or numerically controlled devices capable of winding tape in two or more axes.

**MTCR:** Item 6(1)(b) Tape-laying machines.

---

**Process:** The carbon fiber preform is impregnated with hydrocarbon gas at 700–2000°C via isothermal, pressure gradient, or temperature gradient methods.

**Equipment:** CVD/CVI furnaces, associated piping, valves, pressure and temperature controls.

**MTCR:** Items 7(b)(2) & 7(c)(2) CVD furnaces and nozzles for CVD furnaces.

---

**Process:** The carbon fiber preform is impregnated with hydrocarbon gas at 700–2000°C via isothermal, pressure gradient, or temperature gradient methods.

**Equipment:** Pressure chamber, pressure generator, temperature and pressure controls.

**MTCR:** Item 7(c)(1) Isostatic presses.

---

**Process:** Filaments are interlaced to form a fabric preform.

**Equipment:** Rotating table with a network of rods, fiber spools, drive motors, and lacing needles.

**MTCR:** Item 6(c) Multi-directional, multi-dimensional weaving machines.

---

**Process:** The carbon fiber preform is impregnated with hydrocarbon gas at 700–2000°C via isothermal, pressure gradient, or temperature gradient methods.

**Equipment:** Pressure chamber, pressure generator, temperature and pressure controls.

**MTCR:** Items 7(b)(2) & 7(c)(2) CVD furnaces and nozzles for CVD furnaces.

---

**Process:** Filaments are drawn through a resin bath and wound onto the rotating mandrel.

**Equipment:** Rotating lathe-type machines capable of winding filaments in three or more axes.

**MTCR:** Item 6(1)(a) Filament winding machines.

---

**Process:** Fabrics are treated with resin and cut into strips to make tape.

**Equipment:** Resin bath and cutting machines.

**MTCR:** Item 6(1)(e) Equipment designed or modified for special fiber surface treatment or for producing prepregs and preforms.

---

**Process:** The prepreg tape is wound on a form or mandrel.

**Equipment:** Rotary lathe-type devices similar to filament winding machines, or numerically controlled devices capable of winding tape in two or more axes.

**MTCR:** Item 6(1)(b) Tape-laying machines.

---

**Process:** The carbon fiber preform is impregnated with hydrocarbon gas at 700–2000°C via isothermal, pressure gradient, or temperature gradient methods.

**Equipment:** CVD/CVI furnaces, associated piping, valves, pressure and temperature controls.

**MTCR:** Items 7(b)(2) & 7(c)(2) CVD furnaces and nozzles for CVD furnaces.

---

**Process:** The carbon fiber preform is impregnated with hydrocarbon gas at 700–2000°C via isothermal, pressure gradient, or temperature gradient methods.

**Equipment:** Pressure chamber, pressure generator, temperature and pressure controls.

**MTCR:** Item 7(c)(1) Isostatic presses.

---

**Process:** Filaments are interlaced to form a fabric preform.

**Equipment:** Rotating table with a network of rods, fiber spools, drive motors, and lacing needles.

**MTCR:** Item 6(c) Multi-directional, multi-dimensional weaving machines.

---

**Process:** The carbon fiber preform is impregnated with hydrocarbon gas at 700–2000°C via isothermal, pressure gradient, or temperature gradient methods.

**Equipment:** Pressure chamber, pressure generator, temperature and pressure controls.

**MTCR:** Items 7(b)(2) & 7(c)(2) CVD furnaces and nozzles for CVD furnaces.

---

**Process:** Filaments are drawn through a resin bath and wound onto the rotating mandrel.

**Equipment:** Rotating lathe-type machines capable of winding filaments in three or more axes.

**MTCR:** Item 6(1)(a) Filament winding machines.

---

**Process:** Fabrics are treated with resin and cut into strips to make tape.

**Equipment:** Resin bath and cutting machines.

**MTCR:** Item 6(1)(e) Equipment designed or modified for special fiber surface treatment or for producing prepregs and preforms.

---

**Process:** The prepreg tape is wound on a form or mandrel.

**Equipment:** Rotary lathe-type devices similar to filament winding machines, or numerically controlled devices capable of winding tape in two or more axes.

**MTCR:** Item 6(1)(b) Tape-laying machines.

---

**Process:** The carbon fiber preform is impregnated with hydrocarbon gas at 700–2000°C via isothermal, pressure gradient, or temperature gradient methods.

**Equipment:** CVD/CVI furnaces, associated piping, valves, pressure and temperature controls.

**MTCR:** Items 7(b)(2) & 7(c)(2) CVD furnaces and nozzles for CVD furnaces.

---

**Process:** The carbon fiber preform is impregnated with hydrocarbon gas at 700–2000°C via isothermal, pressure gradient, or temperature gradient methods.

**Equipment:** Pressure chamber, pressure generator, temperature and pressure controls.

**MTCR:** Item 7(c)(1) Isostatic presses.