

# MMR-Unit

## Graphite Material

### Specification

**Release** : 03  
**Status** : Approved  
**Issue Date** : 2022/09/14  
**Project** : MMR-Unit  
**Project Phase** : Basic (Stage 3)

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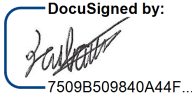

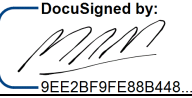


## CONFIGURATION CONTROL

### Document Change History

Rev.	Date	Preparer	Changes
01	2020/11/10	J Potgieter	New document
02	2021/03/01	J Potgieter	Updated after comments from CNL Removed repeated requirements from ASTM/ASME
03	2022/09/14	J Potgieter	Changed irradiated strength testing to compressive based on ASME requirements Updated irradiated points figure Updated material requirements Changed criteria to charge average

### Document Approval

Action	Designation	Name	Signature	Date
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## ABBREVIATIONS

This list contains the abbreviations used in this document.

<b>Abbreviation or Acronym</b>	<b>Definition</b>
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
CSA	Canadian Standards Association
CTE	Coefficient of Thermal Expansion
IIHP	Isomolded, Isotropic- High Purity
MMR™	Micro Modular Reactor
USNC	Ultra Safe Nuclear Corporation
TBD	To be determined

## DEFINITIONS

**Billet-** A graphite artifact with dimensions sufficient to meet the Purchasers requirements.

**Charge-** Billets of a single grade that have been placed together in a furnace for graphitisation.

**Production Lot-** Specified number of billets made in accordance with this specification.

**Purchaser-** The Purchaser is the party that provides the requirements for the manufacture of the raw graphite material and who is responsible for ensuring the quality standards of the Supplier are sufficient.

**Supplier-** The Supplier is responsible for the manufacture of the raw graphite material. This includes the procurement of raw materials and the processing of these raw materials into the finished product.



## **1. INTRODUCTION**

### **1.1. PURPOSE**

The purpose of this document is to provide a specification for the graphite material for use within the USNC MMR™ Unit.

### **1.2. SCOPE**

This specification covers the manufacturing of the raw graphite material, testing, packaging and transportation requirements as well and record keeping.

### **1.3. DOCUMENT LAYOUT**

This document includes an introduction, followed by the material and manufacturing requirements for graphite, the quality assurance requirements and the data needs for the specified material.

## **2. MATERIAL MANUFACTURING REQUIREMENTS**

### **2.1. MATERIAL DESIGNATION**

The graphite provided by the Supplier shall be a fine grained, high purity, isotropic, isomolded nuclear graphite in accordance with ASTM D 7219- “*Standard for Isotropic and Near Isotropic Nuclear Graphite*” [1] class IIHP (Isomolded, Isotropic- High Purity) as well as ASME BPVC Section III Division 5 [2].

The material requirements provided within this specification are in addition to the requirements of those stated in [1] and [2], and shall take preference should a contradiction arise.

### **2.2. RAW MATERIALS**

#### **2.2.1. Fillers**

The maximum filler particle size used in the mix formulation shall be 100  $\mu\text{m}$ .

#### **2.2.2. Forming Lot**

It is preferred that the graphite material used for an MMR™ Unit Graphite Core Assembly shall come from the same forming lot.

### **2.3. MANUFACTURING REQUIREMENTS**

#### **2.3.1. Formulation**

The mix formulation and recycle green mix fraction in the filler shall be recorded and reported to the Purchaser.

#### **2.3.2. Forming**

The green mix shall be formed by iso-molding.

#### **2.3.3. Nominal billet dimensions**

A billet size that is appropriate shall be developed and justified by Supplier and agreed upon by the Purchaser before any order is placed as a result of this specification. The nominal billet size shall produce a usable billet equal to or greater than the usable size specified by the Purchaser.

## 2.4. MATERIAL PROPERTIES

Each graphite production lot shall be tested and shall conform to the following physical, mechanical and chemical property requirements in accordance with [1] and [2].

**Exhibit 2-1: Charge average values**

Property	Unit	Required value	Desired value
Density	kg/m <sup>3</sup>	>1750	>1800
Coefficient of thermal expansion <sup>3,6</sup>	10 <sup>-6</sup> °C <sup>-1</sup>	3.5 - 5.5	4 - 5
Thermal conductivity <sup>3,5</sup>	W/m.K	>110	>120
Isotropy ratio		<1.1	
Tensile strength <sup>3,4</sup>	MPa	>25	>27
Compressive strength <sup>3,4</sup>	MPa	>70	>80
Flexural strength	MPa	>55	>65
Dynamic elastic modulus <sup>3,4</sup>	GPa	9 - 12	9
Boron equivalence <sup>2</sup>	ppm	< 1.5	< 1
Ash content <sup>2</sup>	ppm	< 150	< 50

(1) – Minimum allowable value, (2) - Maximum allowable value, (3) With- Grain, (4) Against-Grain, (5) Measured at room temperature, (6) Mean value when measured over range of 25°C to 500°C.



### **3. QUALITY ASSURANCE**

#### **3.1. GENERAL REQUIREMENTS**

The Supplier shall be responsible for establishing, documenting, implementing, and maintaining a Quality Assurance Program in accordance with CSA N299.3-16 [3] and ASME BPVC Section III Division 5 [2].

The Suppliers Quality Assurance Program shall be audited by the Purchaser for compliance with [3] and [2] before any order of material is placed as a result of this specification.

#### **3.2. QUALITY CONFORMANCE INSPECTION**

##### **3.2.1. Responsibility of Inspection**

The Supplier shall be responsible for the authorized inspection of graphite billets in compliance with [2], and [3]. The Quality Assurance Program created by the Supplier shall detail the inspection of items. This shall cover at least:

- The responsible authorized inspection personal.
- Any inspection hold and witness points during manufacture.
- Any hold or witness points that require additional interaction with the Purchaser or other parties.

The Supplier shall develop and document a testing and inspection plan that shall require acceptance by the Purchaser. The testing and inspection plan shall be audited by the Purchaser for compliance with [3] and [2] and shall be approved by the Purchaser before any order of material is placed as a result of this specification.

##### **3.2.2. Minimum Inspection Requirements**

Graphite billets shall be visually inspected for external flaws. The allowable size, type and number of flaws that are allowable shall be developed and justified by the Supplier and agreed upon by the Purchaser.

All graphite billets shall be non-destructively tested to screen for internal defects. The allowable size, type and number of internal flaws as well as the testing method shall be developed and justified by the Supplier and agreed upon by the Purchaser.

#### **3.3. SAMPLING AND CUTTING**

A statistical sampling and cutting plan shall be developed and justified by the Supplier and agreed upon by the Purchaser. The sampling methods, locations, frequencies and

acceptance criteria shall be approved by the Purchaser before any order of material is placed as a result of this specification.

#### **3.4. REJECTION AND REWORK**

Undamaged portions of the billets that have been damaged may be used provided that the undamaged section meets all other requirements of this Material Specification subject to internal inspection of the undamaged portion.

#### **3.5. CERTIFICATION**

The Supplier shall provide a Certified Material Test Report that affirms the contents of the report are correct and accurate and that all test results and operations performed by the Supplier or its subcontractors are in compliance with this Material Specification.

The Supplier shall transmit all certifications required by [2] Subsection HAB-3862, received from other material organizations or suppliers to the Purchaser in English.

When specific times or temperatures of heat treatment are required by the Material Specification, they shall be reported.

The Quality Systems Certificate number and expiration date shall be shown on the Certified Material Test Report.

#### **3.6. PRODUCT MARKING AND IDENTIFICATION**

Graphite billets may be marked by any method that will not result in harmful contamination or sharp discontinuities and that will sufficiently identify the billet. Vibroetching is the preferred method of marking, however laser engraving is also permitted.

The marking shall indicate the axis of forming.

#### **3.7. PACKAGING, STORAGE AND TRANSPORT**

The detailed procedures for packaging, storage and transport shall be developed by the Supplier and shall be included in the Suppliers Quality Assurance Program.

The graphite billets shall be packaged and stored in a manner that prevents contamination by moisture, dust, oil, grease or any other contaminant that may damage the billet with reference to the materials listed in Exhibit 4-2.

The graphite billets shall be packaged and stored in such a manner that mechanical damage is prevented.

The use of non-powdered gloves or other suitable precautions shall be implemented to prevent contamination during handling.

Provisions shall be made for the use of shock monitors during transportation.

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The identification of billets shall be repeated on the packaging.

### **3.8. DOCUMENTATION REQUIREMENTS**

The Supplier shall provide adequate documentation as required by [1], [2] and [3] in English. This includes, but is not limited to:

- A Quality System Manual that describes the Quality Assurance Program for manufacturing graphite, which shall include all procedures and processes.
- A testing and inspection plan.
- Quality assurance records
- A Manufacturing Specification including a Quality Assurance specimen extraction plan.
- A manufacturing schedule.
- A material qualification report/s
- Production records.
- Inspection records covering batch, billet and sample inspections.
- Material acceptance certificates.

## 4. DESIGN DATA NEEDS

The Supplier shall supply the Purchaser with a datasheet that includes all required material data for the specified grade. All data provided shall be in compliance with [1] and [2] and shall consider sample orientation. Any deviations to these requirements shall be approved by the Purchaser before any order of material is placed as a result of this specification.

### 4.1. AS-MANUFACTURED PROPERTIES

The following as-manufactured properties of the material shall be provided by the Supplier:

- Tensile strength, temperature dependent,
- Compressive strength, temperature dependent,
- Flexural Strength,
- Elastic modulus (dynamic), temperature dependent,
- Elastic modulus (static),
- Poisson's ratio,
- Coefficient of thermal expansion, temperature dependent,
- Critical stress intensity factor ( $K_{Ic}$ ),
- Density,
- Thermal conductivity, temperature dependent,
- Mean grain size,
- Weibull modulus, threshold stress and characteristic strength,

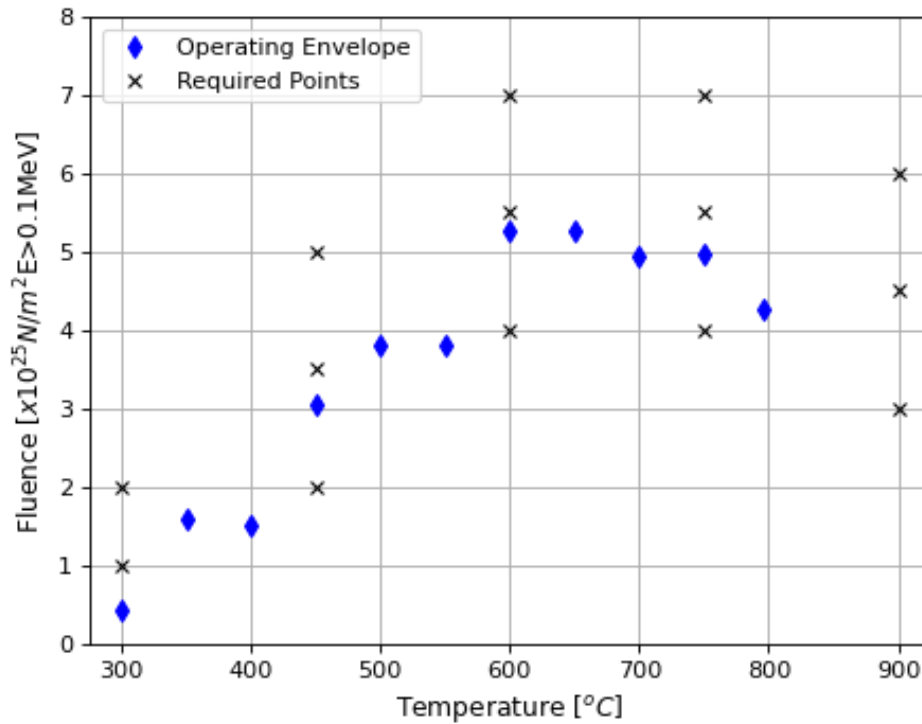
Temperature dependent values are required at at-most 200°C increments from room temperature to at least 1200°C. The mean and standard deviation of each property shall be provided.

### 4.2. IRRADIATED PROPERTIES

The effect of irradiation on the following properties of the material shall be provided by the Supplier:

- Thermal conductivity, temperature dependent,
- Dimensional change (including volume change),
- Primary and Secondary Creep coefficients,
- Coefficient of thermal expansion, temperature dependent,
- Compressive strength, temperature dependent,
- Dynamic Elastic modulus,

Irradiated properties shall be provided at the points displayed in Exhibit 4-1. Post-irradiated temperature-dependent values are required at at-most 200°C increments from room temperature to the irradiation temperature or to 1200°C, whichever is lower. The mean and standard deviation of each property shall be provided.

**Exhibit 4-1: Fluence-Temperature envelope**

### 4.3. OXIDIZED PROPERTIES

The following physical properties shall be provided by the Supplier:

- Gas Permeability
- BET Surface Area
- Open Porosity
- Pore Size distribution
- The reaction rates as detailed in ASTM- D7542-21 [4].

The following post-oxidation properties of the material shall be provided by the Supplier:

- Compressive strength - temperature dependent,
- Dynamic elastic modulus,
- Thermal conductivity - temperature dependent,

Temperature dependent values are required at at-most 200°C increments from room temperature to at least 1200°C. Oxidated material properties shall be measured up to 10% oxidative weight loss in 2% increments. The mean and standard deviation of each property shall be provided.



#### 4.4. CHEMICAL PROPERTIES

The concentration of the substances within as-manufactured billets stated in Exhibit 4-2 shall be provided by the Supplier.

**Exhibit 4-2- Controlled Substances [2]**

Neutron Absorbing	Oxidation-Promoting	Activation Relevant	Metallic Corrosion Relevant	Fissile Elements
Boron	Aluminium	Antimony	Chlorine	Thorium
Cadmium	Barium	Cadmium	Mercury	Uranium
Chlorine	Calcium	Cesium	Sulfur	
Dysprosium	Copper	Chlorine		
Europium	Iron	Cobalt		
Gadolinium	Lead	Europium		
Gold	Magnesium	Gadolinium		
Indium	Manganese	Iron		
Iron	Nickel	Lithium		
Mercury	Potassium	Molybdenum		
Nickel	Silicon	Nickel		
Rhenium	Silver	Nitrogen		
Rhodium	Sodium	Scandium		
Samarium	Titanium	Silver		
Titanium	Strontium	Tantalum		
Tungsten		Terbium		
Vanadium		Thorium		
		Uranium		
		Dysprosium		



## REFERENCES

- [1] ASTM, "D 7219-Standard Specification for Isotropic and Near-Isotropic Nuclear Graphites," 2008.
- [2] ASME, "Boiler and Pressure Vessel Code, Section III, Division 5," 2019.
- [3] Canadian Standards Association, "Quality assurance program requirements for the supply of items and services for nuclear power plants, Category 3," 2016.
- [4] ASTM, "D7542-21 Standard Test Method for Air Oxidation of Carbon and Graphite in the Kinetic Regime," ASTM, 2021.