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Background Information for Addressing Adequacy or Optimization of ASME BPVC Section III, Division 5 Rules for Nonmetallic Core Components

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BACKGROUND INFORMATION FOR ADDRESSING ADEQUACY OR OPTIMIZATION OF ASME BPVC SECTION III, DIVISION 5 RULES FOR NONMETALLIC CORE COMPONENTS

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FOREWORD

The purpose of this document is to provide background information on the scope, development, and verification of elevated-temperature design and construction rules as defined in the ASME Boiler and Pressure Vessel Code ("BPVC"), Section III *Rules for Construction of Nuclear Facility Components*, Division 5 *High Temperature Reactors* Subsection HH, *Class A Nonmetallic Core Support Structures*, Subpart A *Graphite Materials*, 2017 edition. The general requirements applicable to nonmetallic core components are discussed in BPVC Subsection HA *General Requirements*, Subpart B, *Graphite Materials*.

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ABBREVIATIONS AND ACRONYMS

AG	against grain
AGR	Advanced Gas Reactor
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
BPVC	Boiler and Pressure Vessel Code
CDF	cumulative density function
dpa	displacements per atom
DOE	Department of Energy
EIHP	extruded, isotropic, high purity
ENHP	extruded, near-isotropic, high purity
FEA	finite element
IIHP	isomolded, isotropic, high purity
INHP	isomolded, near-isotropic, high purity
JAEA	Japan Atomic Energy Agency
KTA	Kerntechnischer Ausschuss (Nuclear Safety Standards Commission)
MIHP	molded, isotropic, high purity
MNHP	molded, near-isotropic, high purity
NRC	US Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
PDF	probability density function
POF	probability of failure
POS	probability of survival
RSF	reserve strength factor
SF	safety factor
SRC	Structural Reliability Class
VP	verification problem
WG	with grain

1 INTRODUCTION

Before its appearance in the 2011 edition of ASME BPVC, there was no internationally recognized graphite core design code. Although the need for such a code was recognized by stakeholders such as the US Nuclear Regulatory Commission (NRC) and several reactor designer/constructers, it was not until 2002 that ASME formed a project team to initiate a graphite design code. Graphite is used extensively for reactor internal components in high-temperature gas reactor concepts, as it is needed to establish core geometries allowing coolant flow, reactivity control, and shutdown element insertion; serve as a moderator while supporting the nuclear heat generation process; and provide a passive heat removal flow path in certain licensing basis events [1].

Those functions are key to the operation and safety of the reactor system. One critical difference between graphite core components and the pressure vessel is that the graphite core assembly is a structure comprising many hundreds of components. The designers take measures to ensure that the failure of a single component does not compromise the function of the assembly.

The prior approach to graphite design was deterministic, similar to the approach applied for metallic components today. Graphite, with no strength in the plastic regime, was treated as a linear Hookean material. Any component that suffered cracking was considered a “failed component” and was removed. Additionally, only nonirradiated graphite use was addressed. This approach has been found to be inadequate for design and regulatory licensing. Graphite, because of its nature, is inherently cracked; and the absence of cracking cannot be ensured nor used as an indicator of absolute reliability, as it can be for metals.

After assessment, a new probabilistic approach was adopted. It concluded that the designer can allow for cracks in the component but must demonstrate through analysis and testing that the component can maintain the assigned safety function. Moreover, the design should account for the effects of irradiation on the thermal and mechanical properties of the graphite in the design of the graphite core and consider statistical strength variations within a billet, as well as variation from billet to billet due to different production runs. The new approach also does not follow the standard ASME practice of defining primary and secondary stresses but instead uses a combined stress approach that incorporates the largest stress contributors — irradiation-induced stresses and mechanical stress concentrations — as well as lesser stress contributors like combined membrane, bending, and peak stresses.

It was initially envisioned that the design code would be applied for helium-cooled high-temperature reactors, as that was the leading technology at the time.

The purpose of this document is to provide background information on the scope, development, and verification of elevated-temperature design and construction rules as defined in ASME BPVC Section III, Division 5 Subsection HH, Class A *Nonmetallic Core Support Structures,* Subpart A *Graphite Materials*, 2017 edition. The general requirements applicable to nonmetallic core components are discussed in BPVC Subsection HA *General Requirements*, Subpart B, *Graphite Materials*.

Similar to the rules for metallic components, BPVC Section III, Division 5, *High Temperature Reactors* is structured to provide a central location for all aspects of construction for high-temperature reactors, including nonmetallic components or, more specifically, graphite components, in the 2017 edition. For nonmetallic components, according to ASME code terminology, “construction” includes all aspects of Materials (HHA-2000), Design (HHA-3000), Machining, Examination and Testing (HHA-4000), Installation and Examination (HHA-5000), and Nameplates (HHA-8000). The rules stipulate details for material specifications (HHA-I), the requirements for preparing a material data sheet (HHA-II), and the requirements for generating design data for different graphite grades (HHA-III). It also gives reference guidance for consideration of factors such as graphite as a structural material (HHA-A) and the environmental and oxidation effects in graphite (HHA-B).