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for Cogeneration of
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Deliverable D41.13: Final Design Proposal

Low Dose Irradiation

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Summary

This document presents the final design proposal for the low dose irradiation experiment INNOGRAPH-1C and the ARCHER deliverable D41.21

Approval

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This note presents the final design proposal for the low dose irradiation experiment INNOGRAPH-1C and ARCHER deliverable D41.13.

1 Introduction

Graphite is a suitable material to be used as a neutron moderator and reflector in nuclear reactors. Graphite has been used in Advanced Gas-Cooled Reactors, Magnox reactors, RBMK's (a Russian acronym meaning "reactor cooled by water and moderated by graphite"), Research Reactors, Materials Testing Reactors and (Very) High Temperature Reactors ((V)HTR's). Since the end of the 20th century there has been a renewed interest in HTR's. Two prototypes, on in Japan (HTTR) and one in China (HTR-10) are being operated. The development of the Pebble Bed Modular Reactor (PBMR) in South Africa and the Gas Turbine Modular Helium Reactor (GT-MHR) are at an advanced stage. The European Commission is also supporting research projects for the development of HTR technology with the aim to create the technological basis for designing and constructing a HTR in Europe.

A lot of research has been performed on the behaviour of graphite grades in a nuclear environment, because graphite is already being used in reactors for decades. However, these graphite grades are no longer commercially available because the raw materials do not exist anymore. In addition, most data from the past are from low temperature experiments (<550 °C), whereas for HTR's graphite temperatures will generally be higher than 550°C. When graphite is irradiated, graphite crystals are damaged. This damage process results in an initial shrinking followed by swelling, as shown in Figure 1. The development of the curve, i.e. maximum shrinkage, turn around dose, etc., depends on irradiation temperature and graphite grade. Exact data of these curves are of crucial importance for reactor designers. Besides dimensional changes, the physical and mechanical properties change as well as a function of neutron damage.

It has been decided to create a database that contains the data of the materials behaviour of available graphite grades under neutron irradiation at HTR relevant temperatures, in order to be able to design a European HTR. The first step in achieving this is an irradiation experiment that has been carried out under HTR-M1 as part of the 5th Framework Programme. The irradiation experiment, named INNOGRAPH (later INNOGRAPH-1A) has been successfully performed in the High Flux Reactor (HFR) in Petten. The INNOGRAPH-1A irradiation was followed by the INNOGRAPH-1B, -2A, and -2B irradiations, all performed in the RAPHAEL-IP project in the 6th Framework Programme. The INNOGRAPH-2 irradiations were performed at a nominal experiment temperature of 950°C. The INNOGRAPH-1A and -1B irradiation were performed at a nominal experiment temperature of 750°C. The INNOGRAPH-1C irradiation is a successor of the INNOGRAPH-1A and -1B irradiations and will be performed within the framework of the ARCHER project in the 7th Framework Programme. It will give data on changes in dimensions, Dynamic Young's Modulus, coefficient of thermal expansion, and thermal diffusivity (from which the thermal conductivity can be derived) of different graphite grades.

2 Experiment

2.1 Irradiation

Figure 1 shows schematically the volume change with neutron fluence at the two main irradiation temperatures of the HTR irradiation programme. The red boxes on the curves indicate the four different irradiation experiments that have been performed in the 5th and 6th European Framework Programmes. The INNOGRAPH-1C irradiation will be a low dose irradiation, schematically indicated by the blue box in Figure 1. The INNOGRAPH-1C experiment will be a three-cycle irradiation, resulting in a predicted (volume averaged) dpa range of 0.9 to 2.2 dpa. The experiment consists of 8 drums with 3 columns to contain the samples. The rig contains 24 thermocouples to monitor and control temperature during irradiation. The sample holder also contains nine neutron fluence detector sets that will be analysed after the irradiation. The sample holder is filled with helium to prevent oxidation of the graphite specimens. The nominal temperature of the experiment will be 750°C. The top drum of the experiment, containing approximately 30 specimens, will have a nominal temperature of 650°C. The experiment will start in the last quarter of 2012.

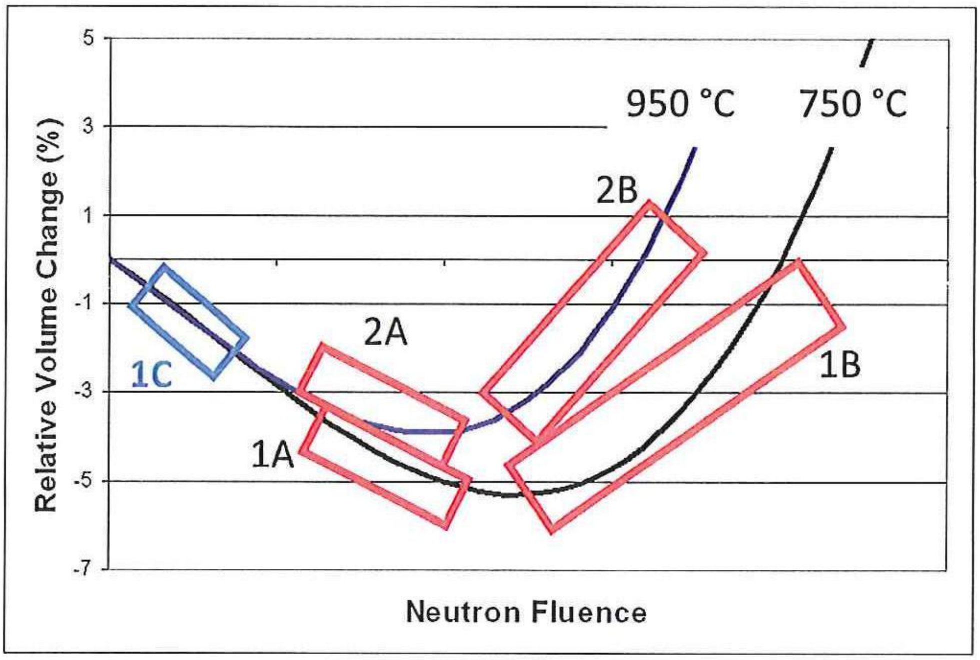

Figure 1. Schematic representation of the volume change of graphite due to irradiation, and the neutron fluence ranges for the INNOGRAPH irradiations. The INNOGRAPH-1C experiment is marked in blue.

2.2 Graphite grades

The selection of the graphite grades for the INNOGRAPH-1C irradiation is, equal to preceding INNOGRAPH irradiations, based on factors such as thermal and mechanical properties, impurity levels, and availability. The four major grades, produced by SGL Carbon and GrafTech, are chosen in such a way that the graphites cover a variety of microstructures. Selecting grades based on different raw materials, i.e. coal tar coke or petroleum coke, and manufacturing methods, i.e. extrusion or vibro-moulding, achieve this. Both manufacturers contribute two major grades.

The minor grades include graphites from three different manufacturers; SGL Carbon, GrafTech, and Toyo Tanso. Among these minor grades are iso-moulded graphites. The Toyo Tanso grades (IG-110 and IG-430) are selected because some irradiation data are available on these materials. These materials therefore act as reference materials. The graphites used in the experiment are listed in Table 1 and Table 2. Table 2 also lists SiC-coated NBG-17, fuel matrix carbon, and HOPG as minor grades. SiC-coated NBG-17 are specimens that are NBG-17 grade graphite with the top and/or bottom of the specimen cylinder coated with 1 to 4 μm of silicon carbide. Fuel matrix carbon made by FNAG is a carbon product under investigation for application in HTR fuel particles. The fuel matrix carbon consists of carbon and 10 per cent of silicon. HOPG stands for highly oriented pyrolytic graphite. These samples consist of graphite with very little spread in the crystal orientation.

Table 1 Selected graphite grades: major grades

Grade	Manufacturer	Coke	Process	#
PCEA	GrafTech	Petroleum	Extrusion	25
PPEA	GrafTech	Pitch	Extrusion	25
NBG-10	SGL	Pitch	Extrusion	25
NBG-18	SGL	Pitch	Vibro-moulding	23

Table 2 Selected graphite grades: minor grades

Grade	Manufacturer	Coke	Process	#
PCIB	GrafTech	Petroleum	Iso-moulding	18
LPEB	GrafTech	Needle	Extrusion	6
LPIB	GrafTech	Needle	Iso-moulding	2
TS5324	GrafTech			5
TS5328	GrafTech			5
NBG-17	SGL	Pitch	Vibro-moulding	18
NBG-25	SGL	Petroleum	Iso-moulding	18
MLRF	SGL		Extrusion	7
SiC-coated NBG-17	SGL	Pitch	Vibro-moulding	5
IG-110	Toyo Tanso	Petroleum	Iso-moulding	14
IG-430	Toyo Tanso	Pitch	Iso-moulding	13
Fuel matrix carbon	FNAG			8
HOPG				4

2.3 Loading matrix

In Table 1 and Table 2, the number of samples per graphite grade is presented in the column marked "#". For major grades more samples are present in the experiment than for minor grades. Figure 2 shows the loading matrix in a graphic representation. For each grade, the dpa values that are expected based on the nuclear calculations are marked. The samples are specified to grain orientation with respect to the sample geometry and location with respect to the original block from which the samples are machined.

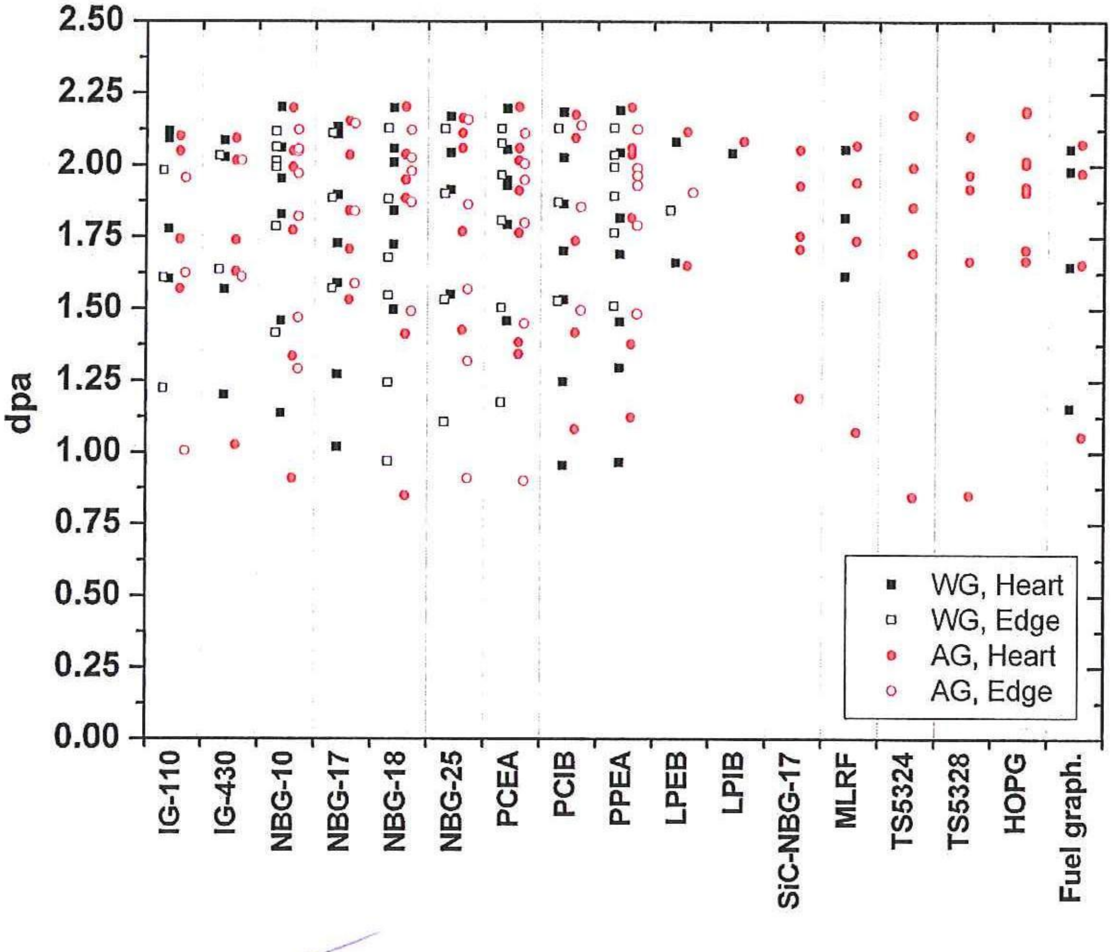

Figure 2. Graphic representation of the loading matrix of the INNOGRAPH-1C irradiation experiment.

Maurits Heijna