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Graphite material procurement & characterisation

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RAPHAEL ***(ReActor for Process heat, Hydrogen And ELectricity generation)***

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Abstract

In the RAPHAEL Integrated Project, three irradiations in the High Flux Reactor (HFR) in Petten are foreseen. The goal of the project is to provide data on the property changes of modern nuclear graphites after irradiation at HTR relevant temperatures (> 550°C). The properties under investigation are dimensional and density changes, the dynamic Young's modulus, the coefficient of thermal expansion and the coefficient of thermal diffusivity. This report describes the material procurement, specimen fabrication and specimen pre-characterisation for the first two of these irradiations.

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INNOGRAPH-1B and INNOGRAPH-2A specimen manufacture and pre-characterization

Deliverable DML3.3: Graphite material procurement & characterisation

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Petten, 23 October 2006

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Summary

In the RAPHAEL Integrated Project, three irradiations in the High Flux Reactor (HFR) in Petten are foreseen. The goal of the project is to provide data on the property changes of modern nuclear graphites after irradiation at HTR relevant temperatures (> 550°C). The properties under investigation are dimensional and density changes, the dynamic Young's modulus, the coefficient of thermal expansion and the coefficient of thermal diffusivity. This report describes the material procurement, specimen fabrication and specimen pre-characterisation for the first two of these irradiations.

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 High Temperature Reactors (HTR's). Recently, there has been a renewal of interest in HTR's. Two prototypes, one in Japan (HTTR) and one in China (HTR-10) are 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 advance stage. The European Commission is also supporting research projects for the development of HTR technology with the aim to create the technological requirements for designing and constructing an HTR in Europe.

Much research has been done on the behaviour of graphite grades in a nuclear reactor 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 the graphite temperatures will generally be higher than 550°C. It is 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. This will allow the 'best' graphite(s) to be chosen, and provide all the data necessary to allow a full core design to be carried out.

Within the RAPHAEL-IP framework, irradiation experiments will be performed at 750°C and 950°C in the High Flux Reactor (HFR) in Petten. In every experiment a few graphites will also be irradiated at the lower temperature of 680°C and 850°C respectively. Four graphites have been selected to be tested as major grades. Two of these are produced by SGL Carbon and two by Graftech. In addition a list is made of minor graphite grades to be included in the experiments with fewer samples. These will also include graphites produced by Toyo Tanso. The following material properties are measured and compared before and after irradiation: specimen dimensions and density, dynamic Young's modulus, coefficient of thermal expansion and thermal diffusivity.

Figure 1 shows schematically the expected volume change with neutron fluence at the two main irradiation temperatures. The boxes on the curves indicate the four different irradiation experiments.

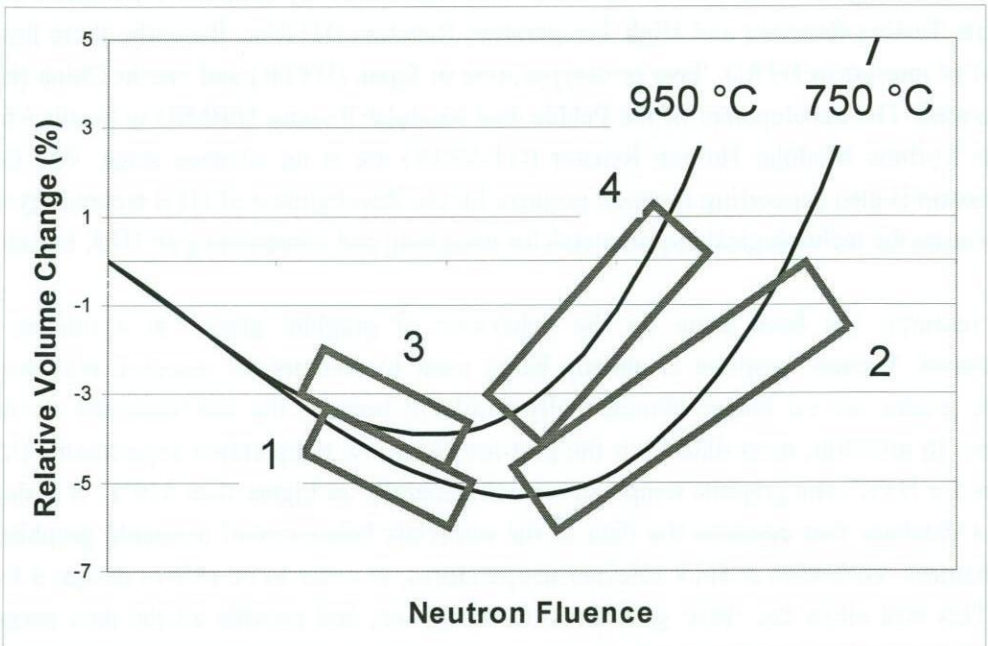

figure 1 Schematic overview of the different irradiation experiments

Box 1, the low dose irradation at 750°C named INNOGRAPH-1A has been performed under HTR-M1 in the 5th Framework Programme and had a target dose of 8 dpa. Box 2, named INNOGRAPH-1B is the high dose (up to ~25 dpa) experiment at the same temperature. Boxes 3 and 4, designated as INNOGRAPH-2A and INNOGRAPH-2B, represent respectively the low to medium dose and the high dose irradiation experiments at 950°C. In order to reach the target dose in as short a time as possible, the high dose experiments (INNOGRAPH-1B/2B) will partly contain specimens, which have been irradiated in the low dose experiments.

This report describes the material procurement, specimen manufacture and specimen pre-characterisation for the INNOGRAPH-1B and INNOGRAPH-2A experiments.

2 Material selection and procurement

2.1 Selected grades

The selection of the graphite grades for the RAPHAEL programme is 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. This is achieved by selecting grades based on different raw materials, i.e. coal tar pitch coke or petroleum coke, and different manufacturing methods, i.e. extrusion or fibro-moulding.

The minor grades include graphites from three different manufacturers, SGL Carbon, Graftech and Toyo Tanso. The minor grades include iso-moulded graphites and graphites based on needle coke. The graphites used in the experiments are listed in tables 1 and 2.

table 1 Selected graphite grades: major grades

Grade	Manufacturer	Coke	Process
PCEA	Graftech	Petroleum	Extrusion
PPEA	Graftech	Pitch	Extrusion
NGB-10	SGL	Pitch	Extrusion
NBG-18	SGL	Pitch	Fibro-moulding

table 2 Selected graphite grades: minor grades

Grade	Manufacturer	Coke	Process
PCIB-SFG	Graftech	Petroleum	Iso-moulding
LPEB/BAN	Graftech	Needle	Extrusion
NBG-20	SGL	Petroleum	Extrusion
NBG-25	SGL	Petroleum	Iso-moulding
NBG-17	SGL	Pitch	Fibro-moulding
IG-110	Toyo Tanso	Petroleum	Iso-moulding
IG-430	Toyo Tanso	Pitch	Iso-moulding

2.2 Material supply

It was decided to collect the graphite blocks at NRG, where the specimens are being machined. Most graphite blocks were delivered in the second half of 2002 before the start of the INNOGRAPH-1A experiment as part of the 5th framework programme. The grades that were not part of this programme but are included in the new experiments (NBG-17, NBG-18 and BAN) were delivered in separate batches in 2005 and the beginning of 2006. In this section the origin of the delivered graphite pieces is described. The location of the pieces in the original fabricated blocks are schematically shown in figure 2. In this figure the z-axes is defined. The z-direction is the extrusion direction (With Grain, WG) for the extruded grades and is perpendicular to the direction of the moulding pressure (z-direction = Against Grain, AG, for the iso- and fibro-moulded grades). The sizes of each piece are given in the following descriptions:

Graftech (UCAR):

PCEA: The original extruded graphite block has a diameter of 450 mm and a length of 950 mm. Three half slices (PCEA 1, PCEA 2 and PCEA 3) with a thickness of 45 mm were delivered at NRG. A summary of the properties that are reported by Graftech is given in Appendix A, Table 5. The reported impurities are given in Appendix B, Table 8.

PPEA: The original extruded graphite block has a diameter of 265 mm and a length of 1800 mm. Three slices (PPEA 1, PPEA 2 and PPEA 3) with a thickness of 45 mm were delivered at NRG. A summary of the properties that are reported by Graftech is given in Appendix A, table 5. The reported impurities are given in Appendix B, table 8.

PCIB (minor grade): The original iso-moulded graphite block has a diameter of 265 mm and a length of 355 mm. Three slices (PCIB 1, PCIB 2 and PCIB 3) with a thickness of 45 mm were delivered at NRG. A summary of the properties that are reported by Graftech is given in Appendix A, Table 5. The reported impurities are given in Appendix B, Table 8.

LPEB / BAN (minor grade): Two billets were sent to NRG. They have a diameter of 140 mm and a length along the extrusion direction of 226 mm. Both were delivered cut into six pieces.

SGL-Carbon:

NBG-10: The original extruded graphite block has a cross section of 250 mm X 520 mm. In the extrusion direction the length was 1500 mm. SGL sent half a cross-section (130 mm X 520 mm), from the centre of the extruded block, with a length of 200 mm. The properties that are reported by SGL are given in Appendix A, table 6. The reported impurities are given in Appendix B, table 9.

NBG-18: The original fibro-moulded block has a cross section of 520 x 570 and a length of 1560 mm. A section 120 mm long is taken out of this block and shipped to NRG. The properties that are reported by SGL are given in Appendix A, table 6.

NBG-17 (minor grade): The original fibro-moulded block has a cross section of 520 x 470 and a length of 1640 mm. A section 120 mm long is taken out of this block and shipped to NRG. The properties that are reported by SGL are given in Appendix A, table 6. The reported impurities are given in Appendix B, table 9.

NBG-25 (minor grade): The original iso-moulded graphite block has a cross section of 510 mm X 320 mm and the length was 1230 mm. SGL sent about half a cross-section (305 mm X 320 mm) with a length of 95 mm from the bottom of the moulded block. The properties that are reported by SGL are given in Appendix A, table 6. The reported impurities are given in Appendix B, table 9.

NBG-20 (minor grade): This grade is produced on a laboratory scale. Four full-sized extruded blocks, produced in the same campaign, were delivered at NRG. The cross section has a diameter of 110 mm and the blocks have a length of 296 mm. The properties that are reported by SGL are given in Appendix A, table 6. The reported impurities are given in Appendix B, table 9.

Toyo Tanso:

IG-110 (minor grade): The original iso-moulded graphite block has a cross section of 610 mm X 315 mm and the length is 950 mm. Toyo Tanso sent a block with a cross section of (200 mm X 300 mm) and a length of 80 mm. The position of this block was in the centre at the bottom of the original block. The properties that are reported by Toyo Tanso are given in Appendix A, table 7. The reported impurities are given in Appendix B, table 10.

IG-430 (minor grade): The original iso-moulded graphite block has a cross section of 600 mm in diameter and the length was 400 mm. Toyo Tanso sent two blocks (IG-430 1, IG-430 2) with a cross section of (200 mm X 300 mm) and a length of 40 mm. The position of this block was near the centre at the bottom of the original block. The properties that are reported by Toyo Tanso are given in Appendix A, table 7. The reported impurities are given in Appendix B, table 10.

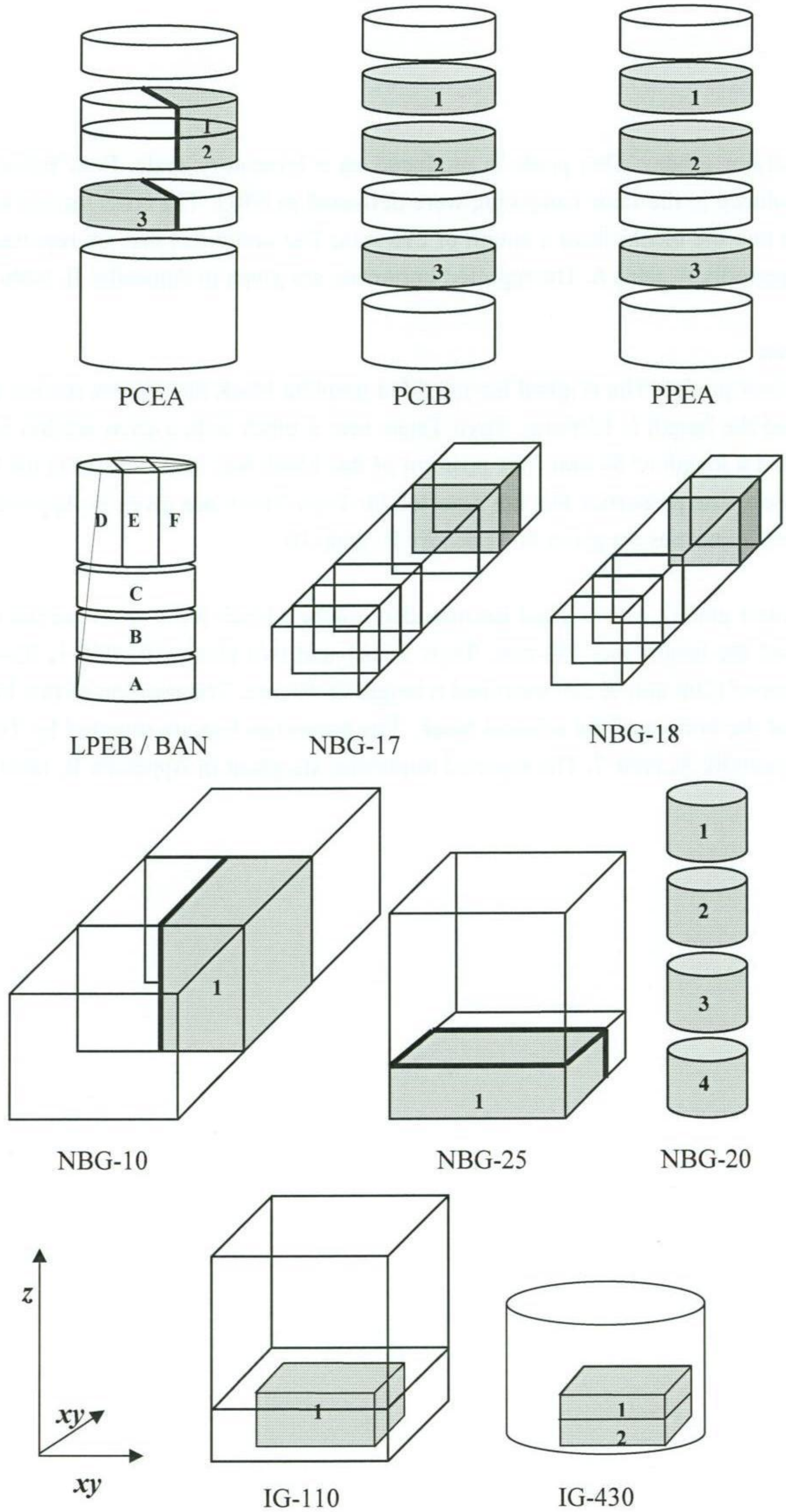

figure 2 Schematical drawings of the origin of the delivered graphite blocks. The sizes in this figure are not in proportion. The sizes are described in the text of section 2.2

3 Specimen type and test matrix

3.1 Specimen type

The specimen shape is cylindrical. The diameter of all specimens is 8 mm and the length is either 6 mm or 12 mm. These sizes are small enough to allow a sufficient number of specimen in the irradiation rig, and big enough to perform reasonably accurate measurements. The specimens with a length of 6 mm are suitable for all type of measurements (dimensional changes, dynamic Young's modulus, coefficient of thermal expansion and thermal diffusivity). The specimens with a length of 12 mm are suitable for measuring dimensional changes, dynamic Young's modulus and coefficient of thermal expansion. The thermal diffusivity measurements cannot be performed on these specimens because a length of 12 mm is too long. These samples are included to have some data points with higher measurement accuracy in mainly the dimensional change measurements.

The cylindrically shaped specimens are flattened by milling a plane with a width of 3 mm along the length. Figure 3 schematically shows the flattening. Producing a plane with a width of 3 mm mills only 1% of the volume of the cylinders. The benefits of this plane are threefold. The first benefit is the possibility to indicate the z-direction from the original graphite blocks in the specimen. The plane is milled perpendicular to the *z*-direction if the axial direction of the cylinder is parallel to the *xy*-direction, and therefore the *z*-direction in the specimen is known after fabrication. The plane is milled on an arbitrary position if the axial direction of the cylinders is parallel to the *z*-direction, because in that case the *z*-direction is already indicated by the axial direction.

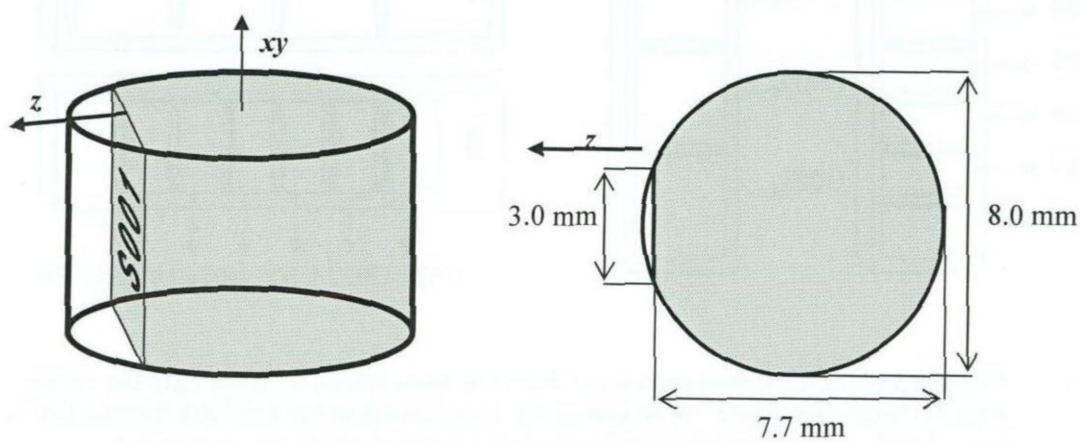

figure 3 Flattening of the specimens. The figure on the left-hand side exaggeratedly shows the flatting of the cylinder. The milled plane is perpendicular to the z-direction when the axial direction of the cylinders in the *xy*-direction. The specimen number is engraved on the plane. The figure on the right-hand side is a top-view of the specimen. The important dimensions are indicated

The second benefit of the plane is that it gives an area to engrave the specimen with a unique code. This code is necessary to easily identify a specimen. The code consists of four characters. The first character is a letter that indicates the graphite manufacturer (S= SGL, U= UCAR (Graftech) and T= Toyo Tanso). The last three characters are numbers.

A third benefit is that the milled plane can act as a marking that defines the measuring positions during the dimensional measurements before and after irradiation.

3.2 Specimen fabrication

Acquiring specimens from the graphite blocks consists of five processing steps. Each step is performed dry to keep the graphite clean.

The first step is extracting squared bars with a cross-section of about 11 mm from the graphite blocks by sawing. The bars are extracted from both the centre and edge region of the blocks. The longitudinal direction of the bars is acquired in two directions, *z* and *xy*. The locations of the bars are indicated in the cutting schemes of the graphite blocks that are shown in Appendix C. The longitudinal direction of the bars will correspond to the longitudinal direction of the specimens. On the bars the z-direction is carved to retain the orientation. Examples of the specimen procurement from the bars are shown in Figure 4. There are more bars acquired than necessary for the amount of specimens that are needed to enable additional specimen procurement.

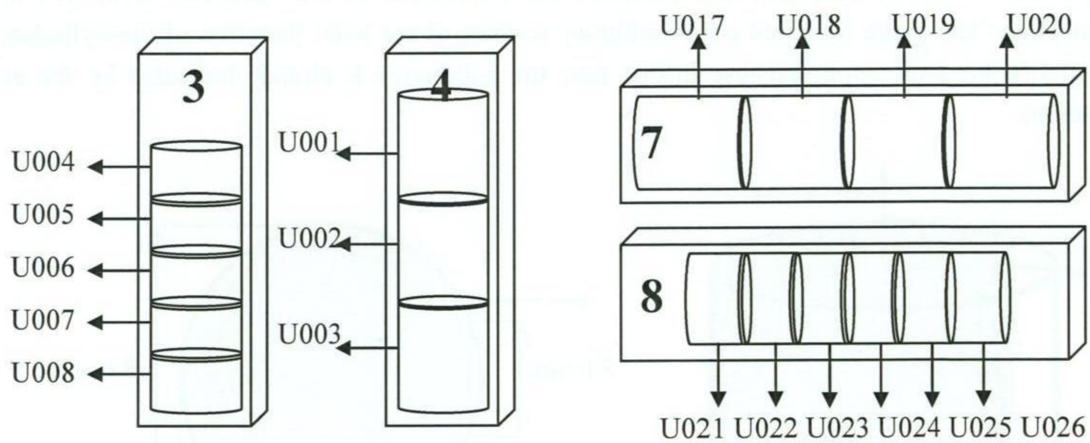

figure 4 Examples of the specimen production from the bars. Above bars are from the centre area of PCEA (see figure 14, Appendix C). Longitudinal lengths of bars 3 and 4 are in the *z*-direction, the longitudinal lengths of bars 7 and 8 are in the *xy*-direction. Specimens U001 t/m U003 have a length of 12 mm, U004 t/m U008 have a length of 6 mm, U017 t/m U020 have a length of 12 mm and U021 t/m U026 have a length of 6 mm.

The second step is turning the squared bars into cylinders with a diameter of 8 mm. The *z* direction of the bars that have the longitudinal directions in the *xy* direction is indicated on the front face of the bar before turning to retain the z-direction. This is not necessary for the bars that have the longitudinal direction in the *z* direction.

The third step is milling a plane with a width of 3 mm over the length of the cylindrical bar. The plane is milled perpendicular to the z-direction if the longitudinal direction of the bar is parallel to the *xy* direction. The plane is milled at an arbitrary position if the longitudinal direction of the bar is parallel to the *z* direction.

The fourth step is cutting the bars in specimens at a length of either 6 mm or 12 mm on a turning lathe. After cutting it is important to carefully flatten the faces of the specimens. This is performed on a turning lathe to have the faces of the cylinders parallel.
The final step is engraving the code on the milled plane.

3.3 Test matrices

The experiments INNOGRAPH-1B and 2A have a similar design. They consist of seven 61 mm drum and one 30 mm drum. Each drum has three channels. Therefore in most drums 30 specimens with a height of 6 mm will fit. In the INNOGRAPH-1B experiment however, the neutron dose will extend to around 25 dpa. This causes the graphite pills to be well into the swelling regime. This has to be accounted for by reducing the number of specimens in a single column from ten to nine. Since therefore the high dose experiment has less room for specimens, the decision has been made to reduce the number of 12 mm specimens to a minimum. Since in INNOGRAPH-1B specimens are reloaded that were part of INNOGRAPH-1A, some 12 mm specimens are included. Tables 3 and 4 give the numbers of each type of specimen for the two experiments.

table 3 Test matrix for the INNOGRAPH-2A experiment

Grade	No. of specimens		Centre		Edge	
	6 mm	12 mm	WG	AG	WG	AG
NBG-10	24	4	6	6	6	6
NBG-25	12	0	5	5	1	1
NBG-18	24	4	6	6	6	6
NBG-17	12	2	5	5	1	1
PCEA	24	4	6	6	6	6
PCIB	12	4	5	5	1	1
PPEA	24	4	6	6	6	6
IG-110	7	0	1	2	2	2
IG-430	5	0	1	2	1	1
LPEB	6	0	2	2	1	1

table 4 Test matrix for the INNOGRAPH-1B experiment. All specimens are 6 mm high with the exception of three irradiated PPEA specimens, all from the centre of the block, two in the AG direction and one in the WG direction

Grade	Number of specimens							
	Unirradiated				Irradiated			
	Centre		Edge		Centre		Edge	
	WG	AG	WG	AG	WG	AG	WG	AG
NBG-10	3	3	5	4	4	5	4	4
NBG-25	3	3	--	--	1	1	2	1
NBG-20	--	--	--	--	2	2	--	--
NBG-18	3	3	4	4	--	--	--	--
NBG-17	4	4	3	3	--	--	--	--
PCEA	3	3	3	4	4	4	4	4
PCIB	3	3	--	--	3	1	1	2
PPEA	3	3	5	4	6	7	--	--
IG-110	1	2	1	2	2	2	1	1
IG-430	2	1	1	2	2	2	1	1
LPEB	2	2	1	1	--	--	--	--

4 Pre-characterization

All the specimens are characterized before irradiation to ensure good qualitative and quantitative assessment of the post-irradiation analysis. The following material properties are determined: individual sample dimensions, thermal conductivity (via thermal diffusivity), coefficient of thermal expansion (CTE), dynamic Young's modulus, mass and volume (hence density). In the post irradiation examination all these properties will be measured of all the specimens, with the exception of thermal diffusivity measurements on 12 mm specimens, which do not fit in the laser flash apparatus. Before irradiation all dimensional, mass and Dynamic Young's modulus measurements are performed, but on a small number (25) of specimens in INNOGRAPH-2A no thermal pre-characterization is performed. These measurements are time-consuming and the scatter between specimens taken out of the same part of the original graphite block is small. Care has been taken that for each specimen, of which no thermal properties are determined, the specimens adjacent to it in the original graphite block are fully characterized.

Sample dimensions are measured before and after the irradiation using Mahr inductive probes (Mahr, type P 2104 MB) with a measurement range of 4 mm and an accuracy of 0.1 μm. The measurement is a comparison of the dimensions of a well-known calibre and the specimen. The volume of each specimen is calculated based on the measured dimensions. The mass of each specimen is determined with a Mettler AT261 scale with an accuracy of 0.01 mg. The dynamic Young's modulus is determined by measuring the velocity of sound in the sample. The velocity of sound is determined with an Agfa-Krautkramer USM 25, using a nominal frequency of 5 MHz. The set-up is calibrated using a steel sample with a known velocity of sound.

The coefficient of thermal expansion is measured using a Netzsch dilatometer DIL402C over the temperature range 25°C-1050°C. Finally, thermal diffusivity was measured using the laser flash method on a Netzsch LFA457 MicroFlash. The thermal diffusivity is determined at nine different temperatures ranging from 25°C to 750°C. For each temperature the diffusivity is measured three times. Thermal conductivity values are derived from the thermal diffusivity data by multiplication with density and specific heat (ASTM C781).

appendix A Properties of the graphite grades as supplied by the manufacturers

table 5 Properties of the graphites from Graftech, as supplied by Graftech

Property	Units	PPEA		PCEA		PCIB	
		WG	AG	WG	AG	WG	AG
Bulk Density	g/cm^3	1.856	1.843	1.839	1.821	1.857	1.858
Specific Resistance	μΩm	9.1	10	7.3	7.8	10.6	11.1
Young's Modulus	GPa	12.5	11.1	11.3	9.9	11.1	10.7
Poisson's Ratio		0.26	0.21	0.23	0.16	0.21	0.18
CTE (30-100°C)	10^{-6} °C^{-1}	4.1	4.3	3.5	3.7	3.8	3.7
Thermal Conductivity (at RT)	W/mK	123	125	162	159	119	112
Flex Strength (4pt)	MPa	34.6	25.2	32.4	23.3	51.3	51.1
Tensile Strength	MPa	18.3	17.5	21.9	16.9	41.8	39.9
Tensile to Failure	%	0.26	0.23	0.39	0.3	0.73	0.63
Compressive Strength	MPa	66.4	82.8	60.8	67.6	108	107.5
Compressive Strain to Failure	%	2.28	2.75	2.61	3.8	3.8	3.8
Gas Permeability	Darcy's	0.0047	0.0019	0.0029	0.0047	0.00091	0.00089
Apparent Porosity	%	8.1	9.1	7.5	8.7	11.6	11.7
Rockwell Hardness	H Scale	85	68	63	51	93	97
Shore Hardness		59	58	50	49	61	61

table 6 Properties of the graphites from SGL-Carbon, as supplied by SGL. For NBG-10 two values are reported the first values indicate the properties at the skin of the extruded product, the second values indicate the properties in the core

		NBG-10		NBG-25	
Property	units	z	xy	z	xy
Density	g/cm^3	1.81 / 1.79		1.815	
Real Density	g/cm^3	2.02 / 2.02		-	
Electrical Resistivity	$\mu\Omega m$	8.4 / 9.1	8.6 / 9.3	10.9	9.5
Young's Modulus	GPa	10.3 / 9.7	9.9 / 9.7	9.9	10.9
Poisson's Ratio		0.2		-	-
CTE (20-200°C)	10^{-6} °C^{-1}	4.2 / 4.1	4.3 / 4.6	4.3	3.9
Thermal Conductivity (at RT)	W/mK	161 / 148	157 / 145	112	126
Flex Strength	MPa	30 / 24	27 / 27	44	48
Tensile Strength	MPa	18 / 20	21 / 18	-	-
Compressive Strength	MPa	70 / 47	60 / 61	93	97
Permeability	cm2/s	0.1 / 0.2	0.2 / 0.2	0.15	0.2
Porosity	%	9.7 / 10.2		10.6	
Hardness HR	10/100	-	-	94	
Oxidation 600°c,8h	%	4.1		-	
Thermal oxidation	µg/g/h	1.1 / 1.5		-	
Rg (big pore size)	µm	14 / 16		-	
Rm (average pore size)	µm	6 / 6		-	

		NBG-17		NBG-18	
Property	units	z	xy	z	xy
Density	g/cm^3	1.892		1.85	
Real Density	g/cm^3	2.04		-	
Electrical Resistivity	$\mu\Omega m$	9.7	9.4	9.7	9.7
Young's Modulus	GPa	11.3	11.5	-	-
Poisson's Ratio		-		-	-
CTE (20-200°C)	10^{-6} °C^{-1}	4.69	4.41	-	-
Thermal Conductivity (at RT)	W/mK	-	-	-	-
Flex Strength	MPa	33.2	32.5	28.7	29.7
Tensile Strength	MPa	23.4	23.8	-	-
Compressive Strength	MPa	85.3	89.5	-	-
Permeability	cm2/s	-	-	-	-
Porosity	%	-		-	
Hardness HR	10/100	-	-	-	
Oxidation 600°c,8h	%	2.7		-	
Thermal oxidation	µg/g/h	-		-	
Rg (big pore size)	µm	-		-	
Rm (average pore size)	µm	6 / 6		-	

table 7 Properties of the graphites from Toyo Tanso, as supplied by Toyo Tanso

		IG-110		IG-430	
Property	Units	xy	z	xy	z
Density	g/cm^3	1.77		1.82	
Electrical Resistivity	$\mu\Omega m$	10.5	9.7	9.9	9.2
Young's Modulus	GPa	9.7	-	10.8	-
Poisson's Ratio		0.15		0.15	
CTE RT-400°C (RT-200°C)	10^{-6} °C^{-1}	3.8 (3.5)	4.2 (3.9)	4.3 (4.0)	4.7 (4.4)
Thermal Conductivity (at RT)	W/mK	140	129	147	138
Flex Strength (4pt)	MPa	42	38	54	49
Tensile Strength	MPa	27.2	-	37.8	-
Compressive Strength	MPa	79	78	98	96
Anisotropy		1.10		1.09	

appendix B Impurities of the delivered graphites as stated by the manufacturers

table 8 Impurities of the graphites from Graftech, according to Graftech (ppm)

	PCEA	PCIB	PPEA
Li	< 0,005	< 0,005	< 0,005
Be	< 0,005	< 0,005	< 0,005
B	1.3	0.33	0.81
C	matrix	matrix	Matrix
N	~ 120	~ 120	~ 100
O	~ 200	~ 400	~ 200
F	< 1	< 1	< 1
Na	< 0,01	< 0,01	< 0,01
Mg	< 0,05	< 0,05	< 0,05
Al	< 0,01	< 0,01	0.03
Si	1.3	0.88	6.1
P	0.19	0.05	0.55
S	7.2	6.3	60
Cl	0.12	0.28	0.37
K	< 0,05	< 0,05	< 0,05
Ca	< 0,05	< 0,05	0.15
Sc	< 0,01	< 0,01	< 0,01
Ti	0.03	0.01	0.05
V	0.07	0.02	< 0,005
Cr	< 0,1	< 0,1	< 0,1
Mn	< 0,005	< 0,005	< 0,005
Fe	0.04	0.03	< 0,01
Co	< 0,01	< 0,01	< 0,01
Ni	< 0,01	< 0,01	< 0,01
Cu	< 0,05	< 0,05	< 0,05
Zn	< 0,05	< 0,05	< 0,05
Ga	< 0,1	< 0,1	< 0,1
Ge	< 0,1	< 0,1	< 0,1
As	< 0,1	< 0,1	< 0,1
Se	< 0,1	< 0,1	< 0,1
Br	< 0,1	< 0,1	< 0,1
Rb	< 0,01	< 0,01	< 0,01
Sr	< 0,01	< 0,01	< 0,01
Y	< 0,05	< 0,05	< 0,05
Zr	< 0,01	0.02	0.07
Nb	0.03	< 0,01	0.05
Mo	< 0,01	< 0,01	< 0,01
Ru	< 0,05	< 0,05	< 0,05
Rh	< 0,05	< 0,05	< 0,05
Pd	< 0,05	< 0,05	< 0,05
Ag	< 0,1	< 0,1	< 0,1
Cd	< 0,1	< 0,1	< 0,1
In	< 0,1	< 0,1	< 0,1
Sn	< 0,01	< 0,01	< 0,01
Sb	< 0,01	< 0,01	< 0,01
Te	< 0,01	< 0,01	< 0,01
I	< 0,01	< 0,01	< 0,01
Cs	< 0,01	< 0,01	< 0,01
Ba	< 0,05	< 0,05	< 0,05
La	< 0,01	< 0,01	< 0,01
Ce	< 0,01	< 0,01	< 0,01
Pr	< 0,01	< 0,01	< 0,01
Nd	< 0,01	< 0,01	< 0,01
Sm	< 0,01	< 0,01	< 0,01
Eu	< 0,01	< 0,01	< 0,01
Gd	< 0,01	< 0,01	< 0,01
Tb	< 0,01	< 0,01	< 0,01
Dy	< 0,01	< 0,01	< 0,01
Ho	< 0,01	< 0,01	< 0,01
Er	< 0,01	< 0,01	< 0,01
Tm	< 0,01	< 0,01	< 0,01
Yb	< 0,01	< 0,01	< 0,01
Lu	< 0,01	< 0,01	< 0,01
Hf	< 0,01	< 0,01	< 0,01
Ta	< 5	< 5	< 5
W	< 0,01	< 0,01	< 0,01
Re	< 0,05	< 0,05	< 0,05
Os	< 0,01	< 0,01	< 0,01
Ir	< 0,01	< 0,01	< 0,01
Pt	< 0,01	< 0,01	< 0,01
Au	< 0,05	< 0,05	< 0,05
Hg	< 0,5	< 0,5	< 0,5
Tl	< 0,01	< 0,01	< 0,01
Pb	< 0,01	< 0,01	< 0,01
Bi	< 0,01	< 0,01	< 0,01
Th	< 0,005	< 0,005	< 0,005
U	< 0,005	< 0,005	< 0,005

table 9 Impurities of graphites from SGL-carbon, according SGL (ppm)

NBG-25			
Ag	< 0,01	Na	0.01
Al	0.06	Nb	< 0,01
Au	< 0,06	Nd	< 0,01
B	< 0,03	Ni	0.2
Ba	0.001	Pb	< 0,06
Be	< 0,001	Pr	< 0,05
Bi	< 0,03	Re	< 0,01
Ca	0.06	Rh	< 0,01
Cd	<0,005	Ru	< 0,01
Ce	<0,02	S	0.6
Cl	7	Sb	< 0,05
Co	<0,005	Sc	< 0,005
Cr	<0,005	Se	< 0,01
Cu	0.008	Si	0.3
Dy	<0,005	Sm	< 0,005
Eu	<0,005	Sn	< 0,02
Fe	0.09	Sr	< 0,005
Ga	< 0,02	Ta	< 0,01
Gd	< 0,005	Te	< 0,03
Ge	< 0,03	Th	< 0,01
Hf	< 0,01	Ti	< 0,005
Hg	< 0,05	Tl	< 0,08
In	< 0,03	U	< 0,02
K	< 0,01	V	< 0,005
La	< 0,005	W	0.01
Li	< 0,005	Y	< 0,05
Mg	0.01	Zn	0.01
Mn	< 0,002	Zr	< 0,03
Mo	< 0,02		

	NBG-10	NBG-17	NBG-20
B	0.4	0.8	1
Si	45	15	3
Fe	3	12.8	9
Ca	5	18.8	8
V	0.2	1.1	8
Ni	0.2	2.7	1
Ti	0.4	2.6	2
W	0.2	--	
Co	<0,1	<0.1	<0,1
Ag			
Al	<0,1	3.3	10
Ba	0.3		0.7
Be	-		<0,1
Bi			
Cd	<0,1		-
Cr	<0,1		0.3
Cu	<0,1		<0,1
K			
Li	<0,1		-
Mg	0.5	<1.5	
Mn	<0,1		<0,1
Mo	0.1		<0,1
Na	0.2	3.6	-
P	0.6		2
Pb	<0,1		<0,1
S			
Sn			
Sr	<0,1		0.4
Zn	<0,1	0.2	5

table 10 Impurities of graphites from Toyo Tanso, according Toyo Tanso (ppm)

	IG-110	IG-430
Ash Content	< 10	< 10
B	< 0.1	< 0.1
Co	< 0.001	< 0.001
Cd	< 0.07	< 0.07
Gd	< 0.05	< 0.05
Li	< 0.01	< 0.01
Sm	< 0.05	< 0.05
Other Elements	0.001□0.08	0.001□0.08

appendix C Cutting schemes of the graphite blocks

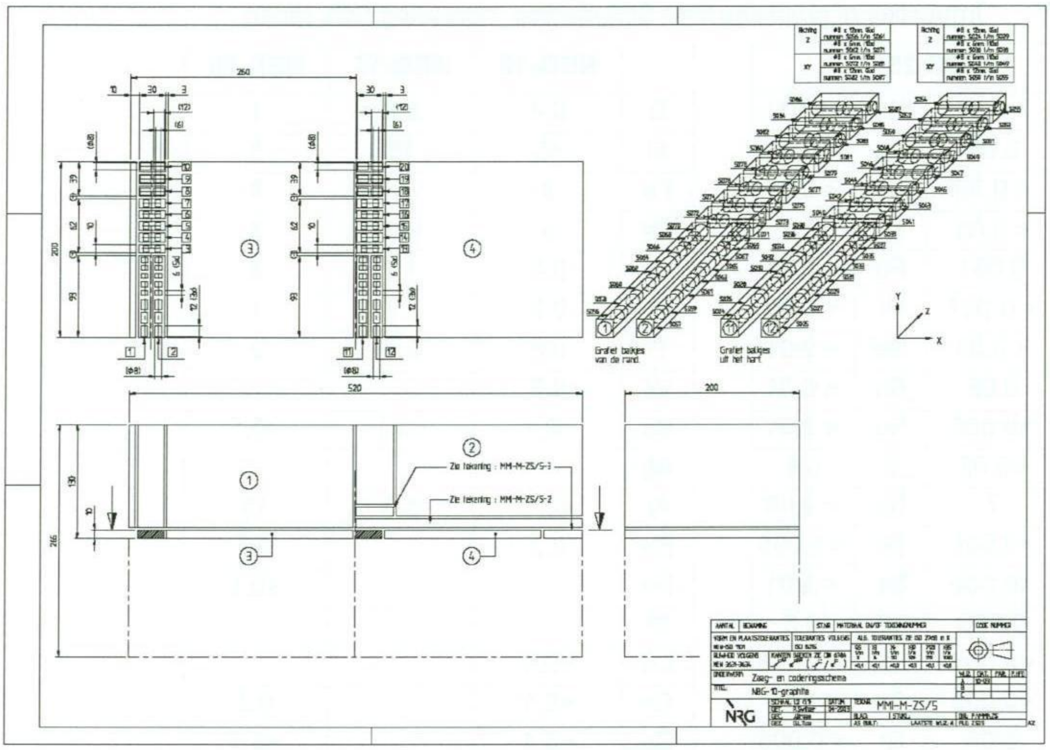

figure 5 Cutting scheme for NBG-10 graphite block. First batch

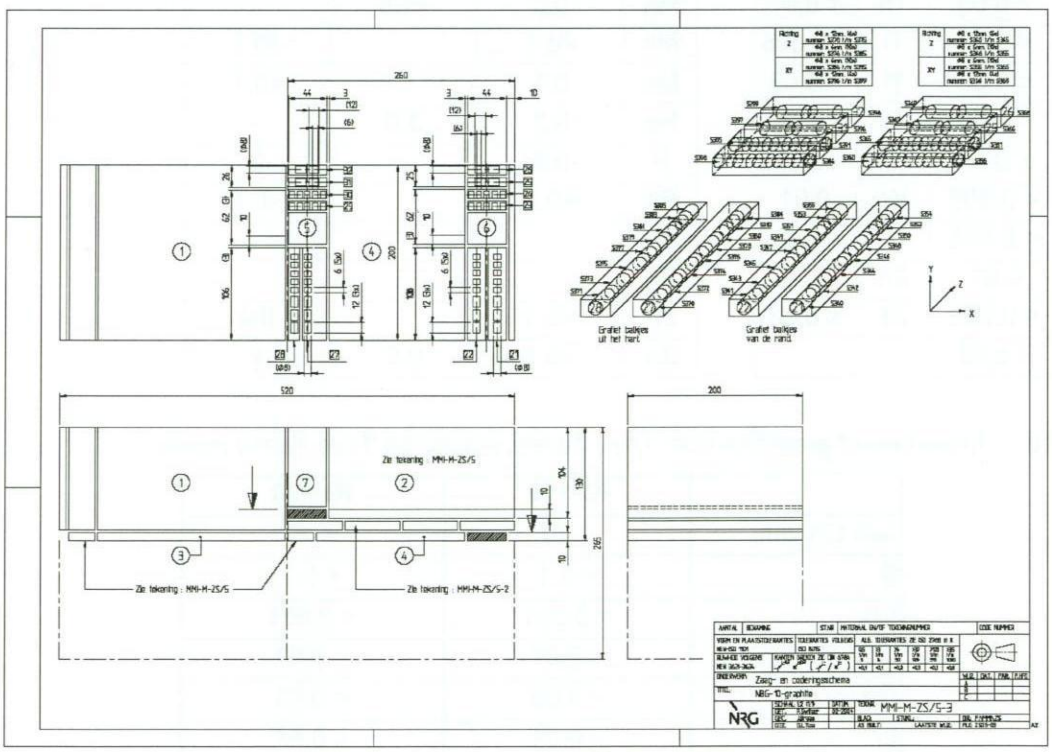

figure 6 Cutting scheme for NBG-10 graphite block. Second batch

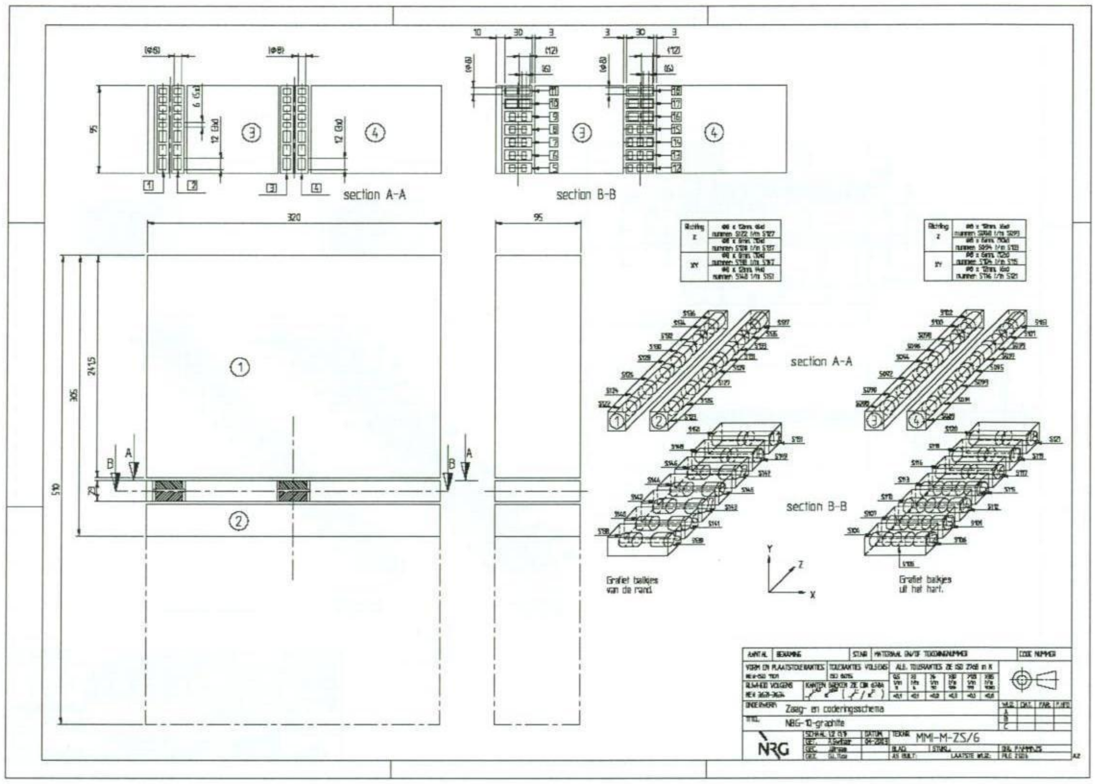

figure 7   Cutting scheme for NBG-25 graphite block. First batch

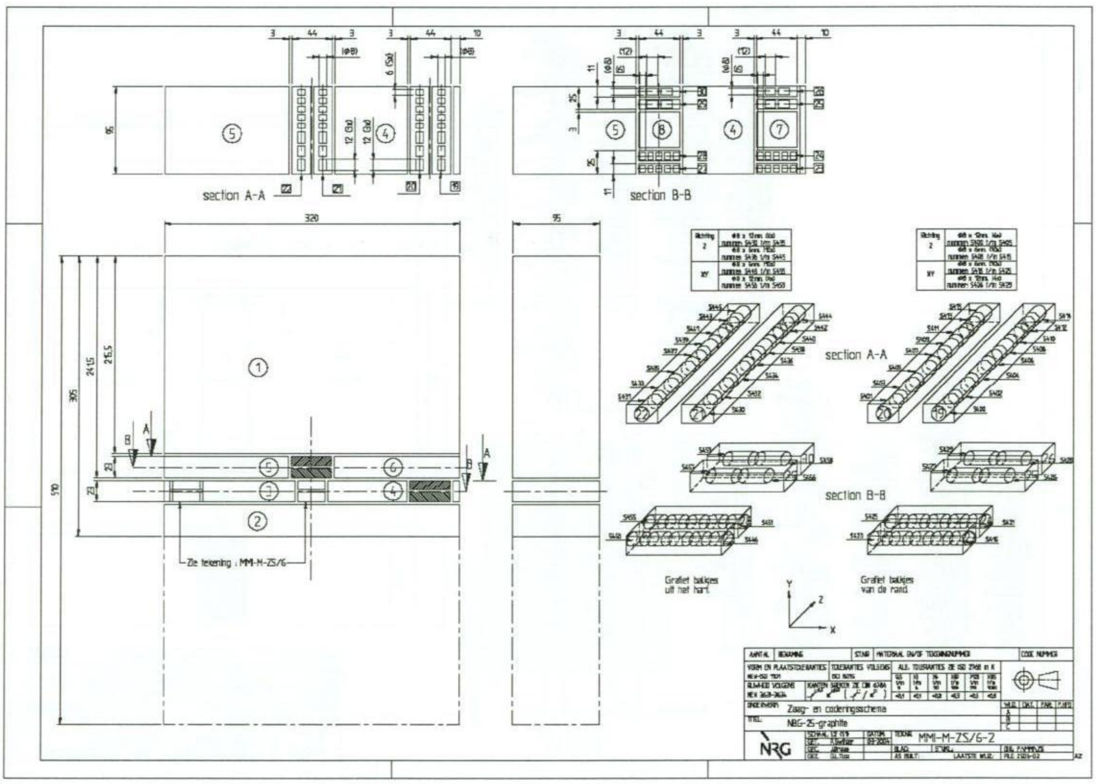

figure 8   Cutting scheme for NBG-25 graphite block. Second batch

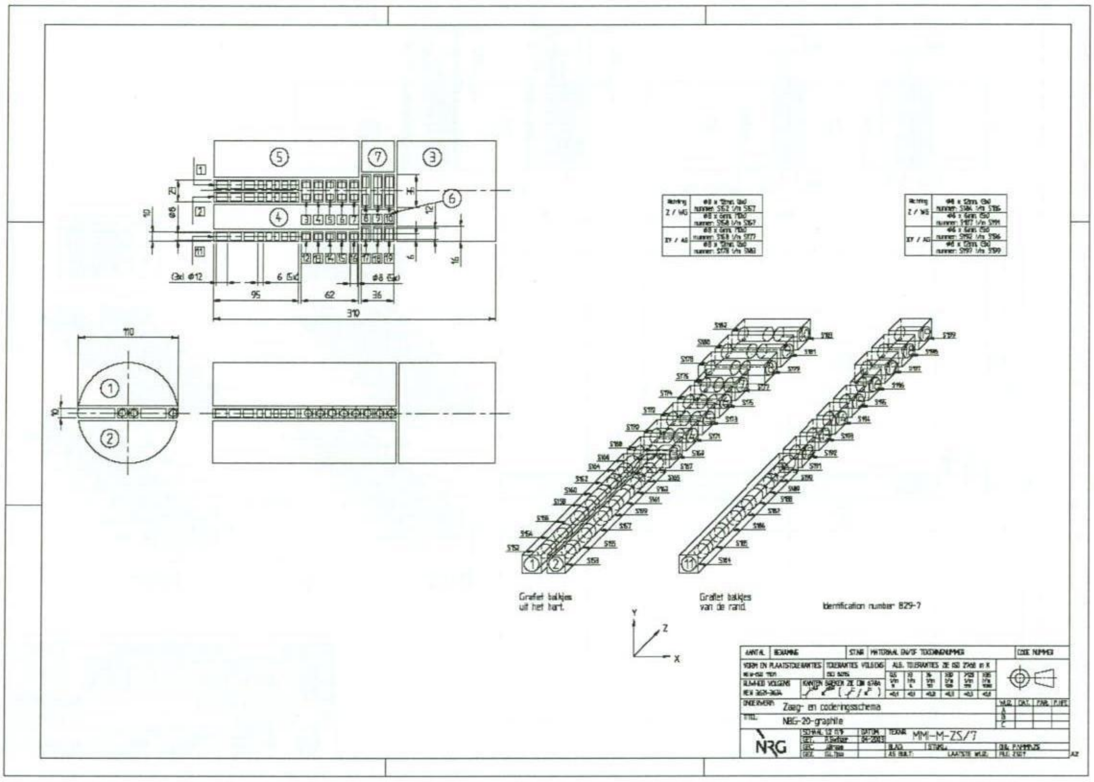

figure 9	Cutting scheme for NBG-20 graphite block

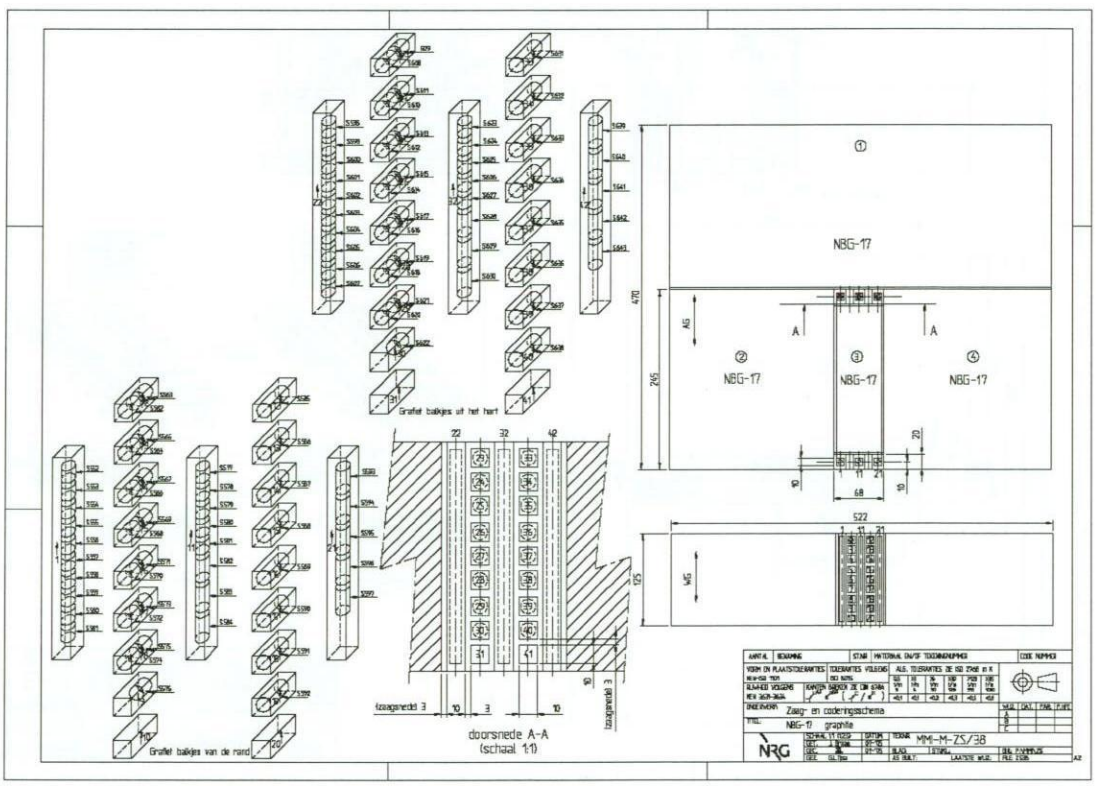

figure 10	Cutting scheme for NBG-17 graphite block

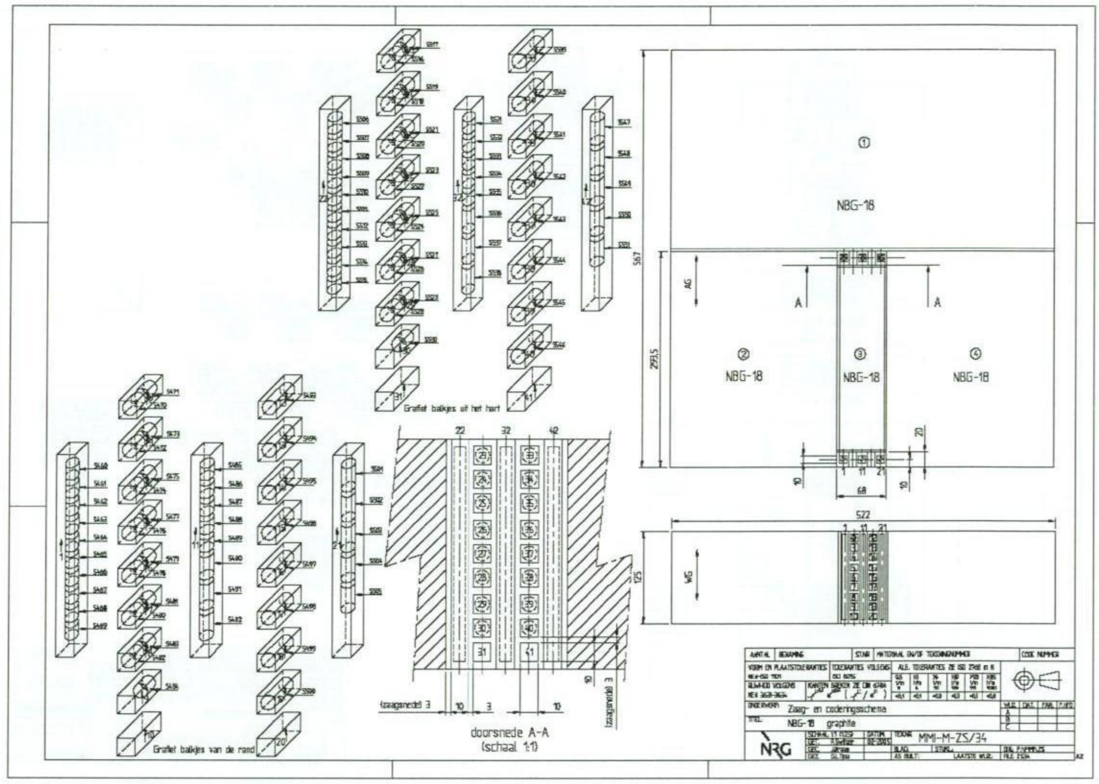

figure 11 Cutting scheme for NBG-18 graphite block

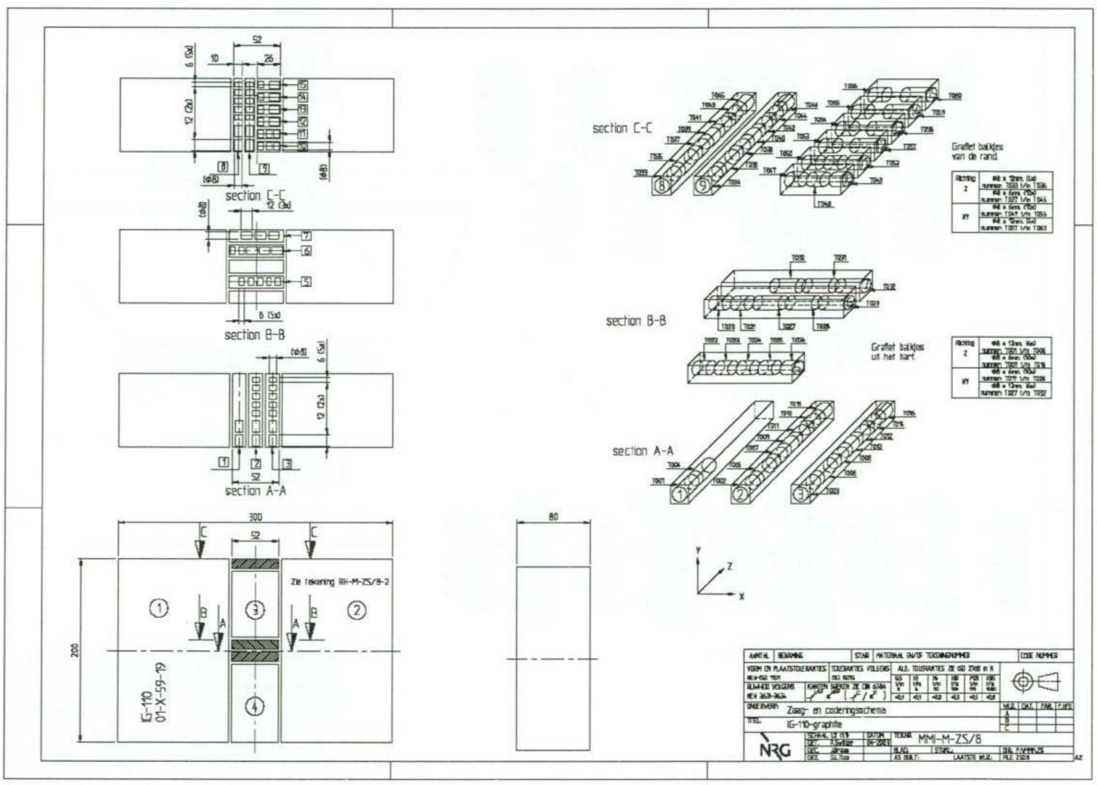

figure 12 Cutting scheme for IG-110 graphite block

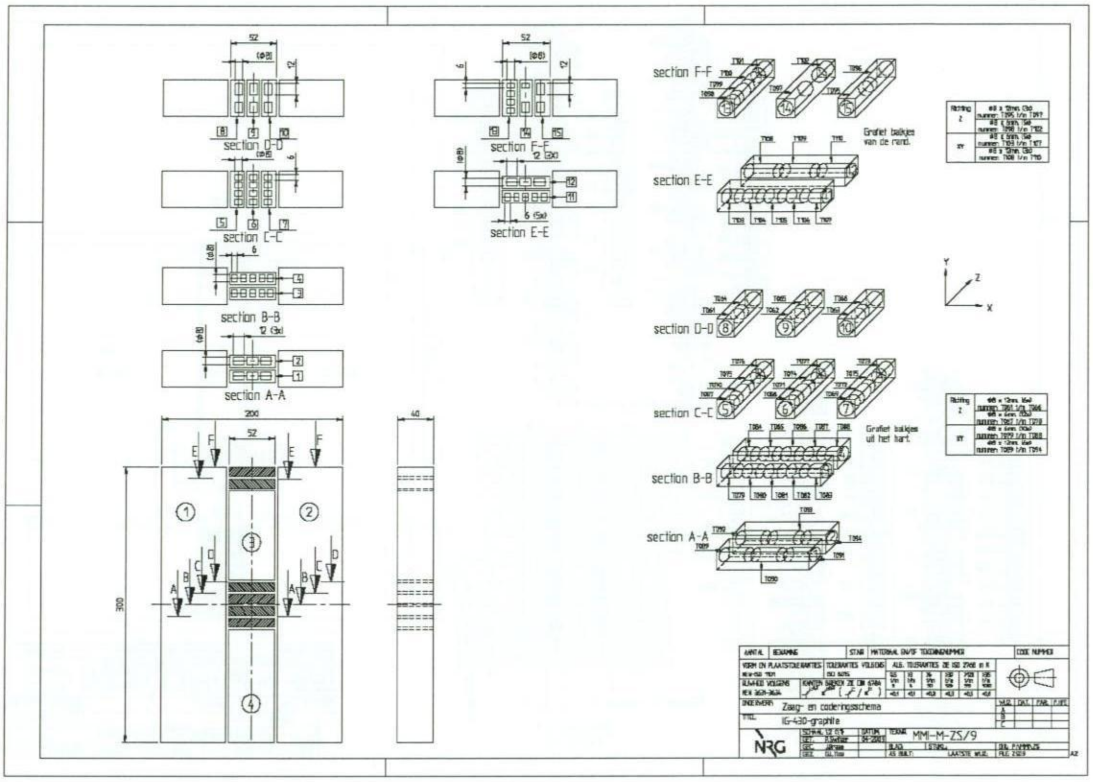

figure 13 Cutting scheme for IG-430 graphite block

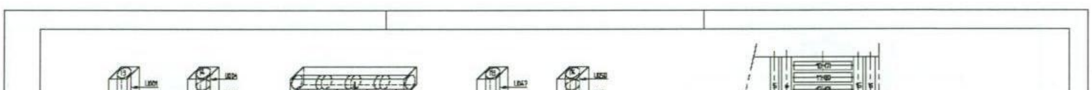

figure 14 Cutting scheme for PCEA graphite block

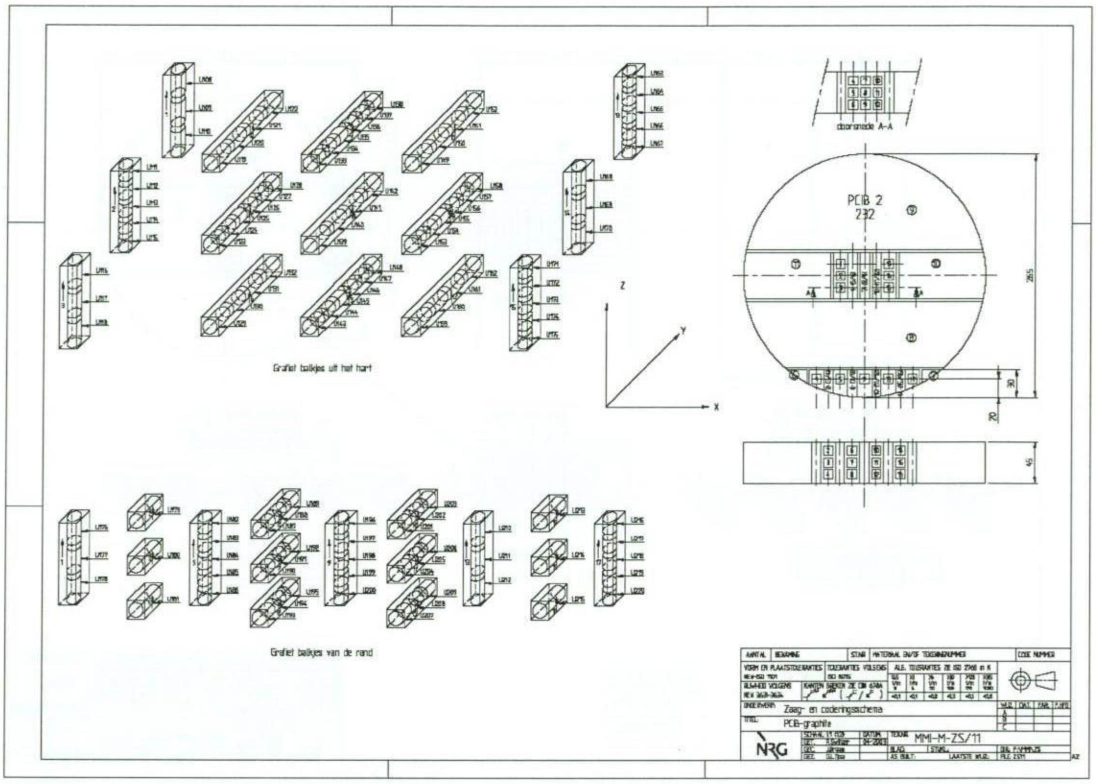

figure 15   Cutting scheme for PCIB graphite block

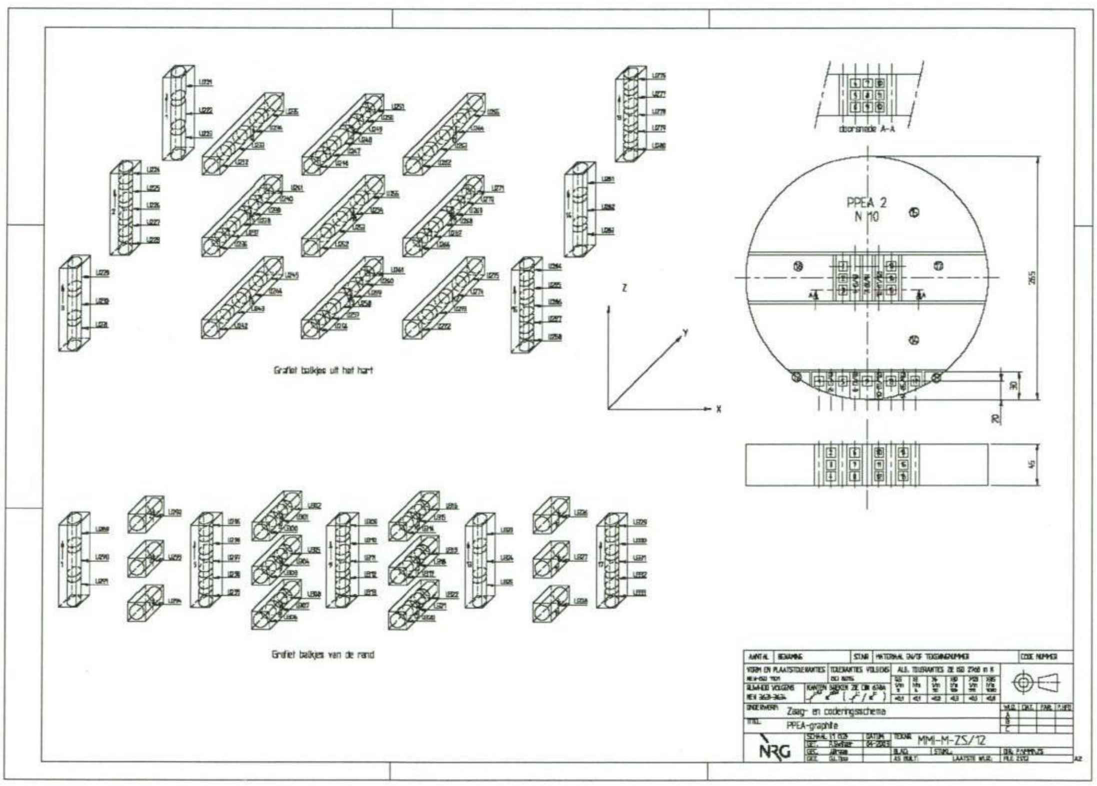

figure 16   Cutting scheme for PPEA graphite block

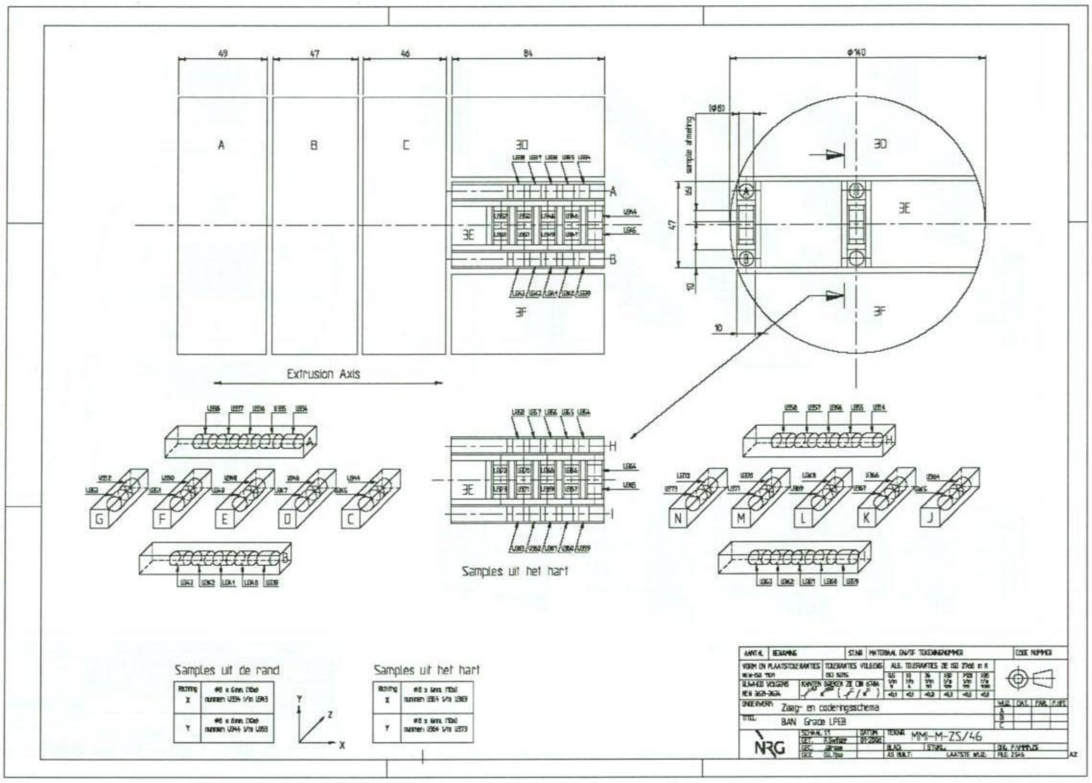

figure 17 Cutting scheme for LPEB graphite block