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HTR-M1 Report on specimen fabrication and procurement for the graphite irradiation tests

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Summary

This report describes specimen fabrication and procurement of the graphites that will be studied in the HTR-M1 project. The goal of the project is to provide data on the property changes of modern nuclear graphites after irradiation at a HTR relevant temperatures (> 550°C). The property changes that will be investigated are dimensional changes, dynamic Young's modulus changes, coefficient of thermal expansion changes and coefficient of thermal diffusivity changes. The irradiation experiment is called INNOGRAPH and will be carried out in the High Flux Reactor in Petten. The material deliveries from the graphite manufactures, specimen types, test matrix and specimen fabrication will be discussed in this report.

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 a 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. A review of the available data on the irradiation behaviour of graphites at high temperatures is given in [1].
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.

The first step in achieving this is an irradiation experiment carried out under HTR-M1 as part of the 5th Framework Programme. The irradiation experiment (called INNOGRAPH) will be performed in the High Flux Reactor (HFR) in Petten. It will give data on dimensional changes, Dynamic Young's Modulus changes, Coefficient of Thermal Expansion changes and Thermal Diffusivity Coefficient changes (from which the thermal conductivity coefficient can be obtained) of five graphite grades. In addition, some specimens of other grades may be included in the experiment, if there is enough space in the irradiation rig. The material selection and testing requirements are described in[2].

This report describes the material deliveries from the graphite manufacturers, the specimen type, test matrix and specimen fabrication.

2 Grades and material supply

2.1 Grades

The selection of the graphite grades for the HTR-M1 programme is based on factors like properties, impurity levels and availability. The 5 major grades 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 manufacturing methods, i.e. extrusion or iso-moulding.
There are three graphite manufacturers selected: Graftech (UCAR), SGL-Carbon and Toyo Tanso. The first two companies contribute two grades and Toyo Tanso contributes one grade. The Toyo Tanso grade (IG-110) is selected because some irradiation data are available on this material, and is therefore acting as a kind of reference material. The five major grades are given in table 1.
All three companies contribute one extra grade in the case there is some space left in the irradiation rig. These grades are in development and some preliminary irradiation data may give an indication of the suitability of the materials for future experiments. It should be noted that not a full batch of these specimens will be tested. These grades are referred to as minor grades. The minor grades are given in table 2.

table 1 Selected graphite grades: major grades

Grade	Manufacturer	Coke	Process
PCEA	Graftech	Petroleum	Extrusion
PCIB-SFG	Graftech	Petroleum	Iso-moulding
NGB-10	SGL	Pitch	Extrusion
NBG-25	SGL	Petroleum	Iso-moulding
IG-110	Toyo Tanso	Petroleum	Iso-moulding

table 2 Selected graphite grades: minor grades

Grade	Manufacturer	Coke	Process
PPEA	Graftech	Pitch	Extrusion
NGB-20	SGL	Petroleum	Extrusion
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. The graphite blocks were delivered in the second half of 2002. 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 1. In this figure the z-axes is defined. The z-direction is the extrusion direction (With Grain, WG) for the extruded grades and perpendicular to the direction of moulding pressure (z-direction= Against Grain, AG, for the 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 A1. The reported impurities are given in Appendix B, Table B1.

PCIB: 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 A1. The reported impurities are given in Appendix B, Table B1.

PPEA (minor grade): 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 A1. The reported impurities are given in Appendix B, table B1.

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 send 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 A2. The reported impurities are given in Appendix B, table B2.

NBG-25: The original iso-moulded graphite block has a cross section of 510 mm X 320 mm and the length was 1230 mm. SGL send 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 A2. The reported impurities are given in Appendix B, table B2.

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 A2. The reported impurities are given in Appendix B, table B2.

Toyo Tanso:
IG-110: The original iso-moulded graphite block has a cross section of 610 mm X 315 mm and the length is 950 mm. Toyo Tanso send 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 A3. The reported impurities are given in Appendix B, table B3.

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 send 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 A3. The reported impurities are given in Appendix B, table B3.

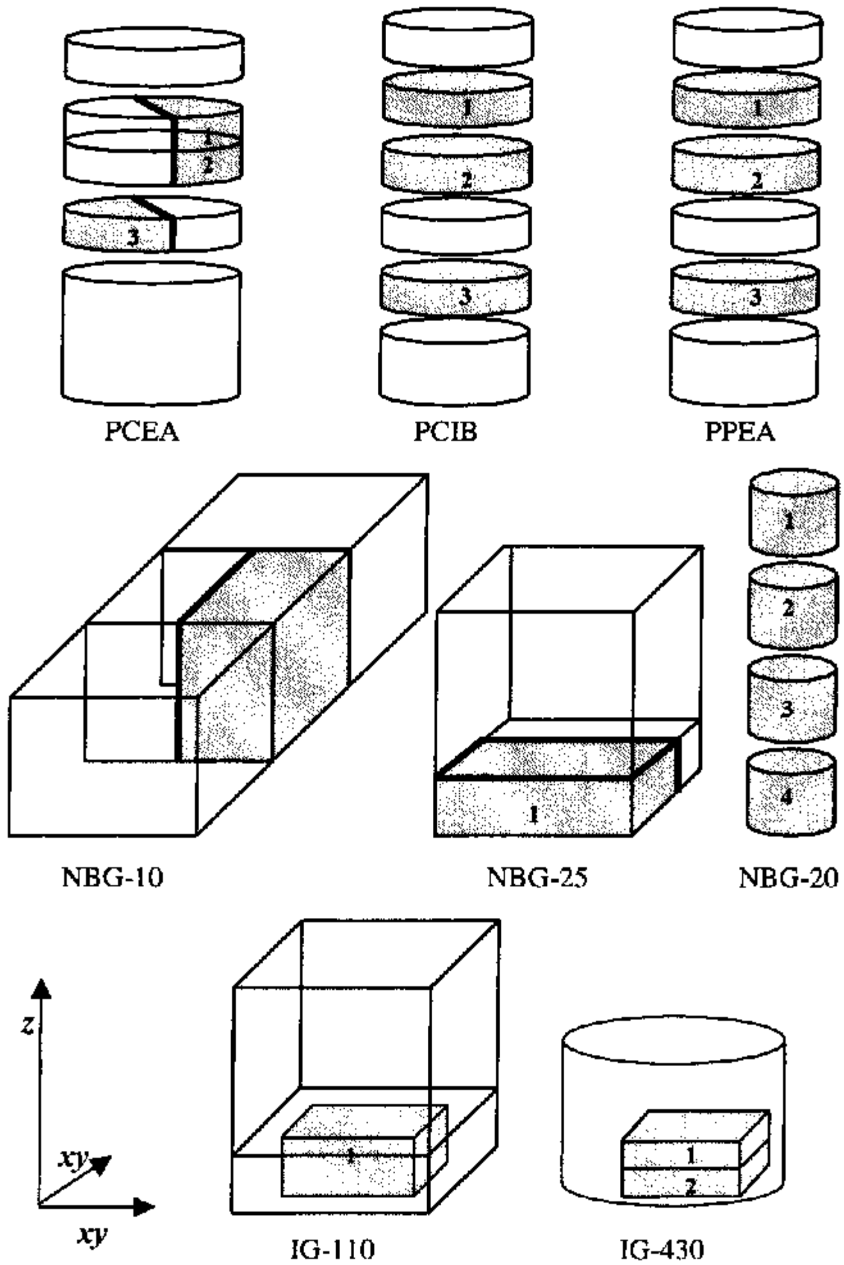

figure 1 Schematical drawings of the origin of the delivered graphite blocks. The sizes in this figure are not in proportion. The sizes are described in the text of section 2.2.

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 Coefficient). 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 Coefficient 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 2 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.

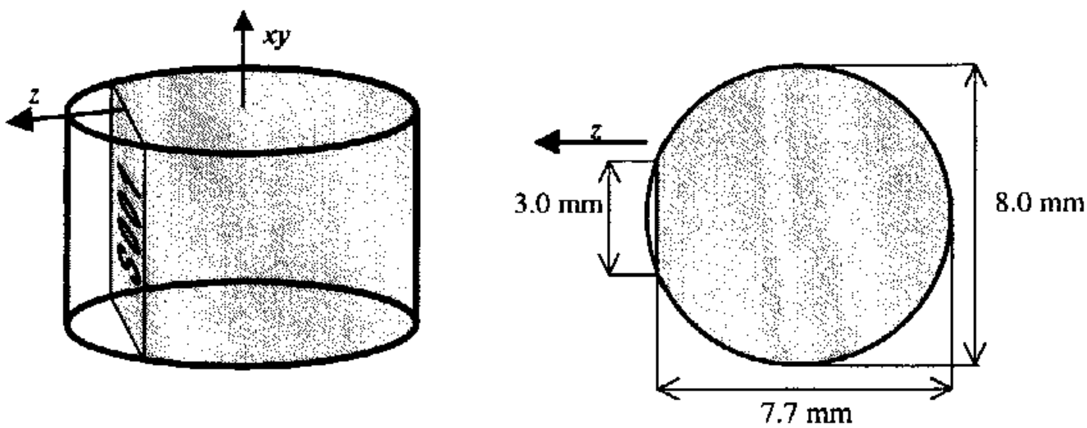

figure 2 Flattening of the specimens. The figure on the left-hand side exaggeratedly shows the flatting of the cylinder. The milled plane is perpendicular to the *z*-direction when the axial direction of the cylinders in the *xy*-direction. The specimen number is engraved on the plane. The figure on 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 an 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 Test matrix

For each major grade 30 specimens can be investigated, assuming that the irradiation rig is able to contain 150 specimens. This means 15 specimens per main direction (z and xy) per grade. The specimens are acquired from the centre as well as near the edge of the blocks to get representative results of the entire graphite blocks. The quantities of the specimens that will be included in the INNOGRAPH are given in table 3.

table 3 Number of specimens of the major grades that will be included in the irradiation experiment INNOGRAPH.

Grade	Direction	Centre		Edge	
		l= 6 mm	l= 12 mm	l= 6 mm	l= 12 mm
PCEA	*z*	5	3	5	2
	xy	5	3	5	2
PCIB-SFG	*z*	5	3	5	2
	xy	5	3	5	2
NGB-10	*z*	5	3	5	2
	xy	5	3	5	2
NBG-25	*z*	5	3	5	2
	xy	5	3	5	2
IG-110	*z*	5	3	5	2
	xy	5	3	5	2

table 4 Preliminary number of specimens of the major grades that will be included in the INNOGRAPH, depending on space in the irradiation rig.

Grade	Direction	Centre		Edge	
		l= 6 mm	l= 12 mm	l= 6 mm	l= 12 mm
PPEA	*z*	0-5	-	-	-
	xy	0-5	-	-	-
NBG-20	*z*	0-5	-	-	-
	xy	0-5	-	-	-
IG-430	*z*	0-5	-	-	-
	xy	0-5	-	-	-

Specimens with a length of 6 mm will be included from the minor grades if there is sufficient space in the irradiation rig. From each minor grade the same amount of specimens will be included. Table 4 shows the preliminary maximum numbers of specimens of the minor grades.

The measurements of the coefficient of thermal expansion (α) and coefficient of thermal diffusivity (a) up to a temperature of about 700°C will take a full day due to heating and cooling of the specimen. Performing these measurements on all 150 to 180 specimens before irradiation will take more than 30 weeks. To save time, not all samples will be measured on α and a before irradiation. The target is to do these measurements on 10 specimens before irradiation from each of the major grades.

Approximate reference values of α and a of the specimens that have not been measured in advance should be known to be able to use the post-irradiation data, because the properties before and after irradiation will be directly compared. Therefore, from every irradiated specimen for which no α and a have been measured, there should be α and a data available of a specimen that was located adjacent to the irradiated sample in the original graphite block. Two variants will be used in the project to achieve this.

The first variant is that from a row of five specimens the two outer and centre specimen will be measured before the irradiation experiment. The second and fourth specimen will be irradiated but not measured before the irradiation experiment The α and a values of the second and fourth specimen will be estimated from their two neighbouring specimens (see figure 3a). These specimens will be called neighbour specimens.

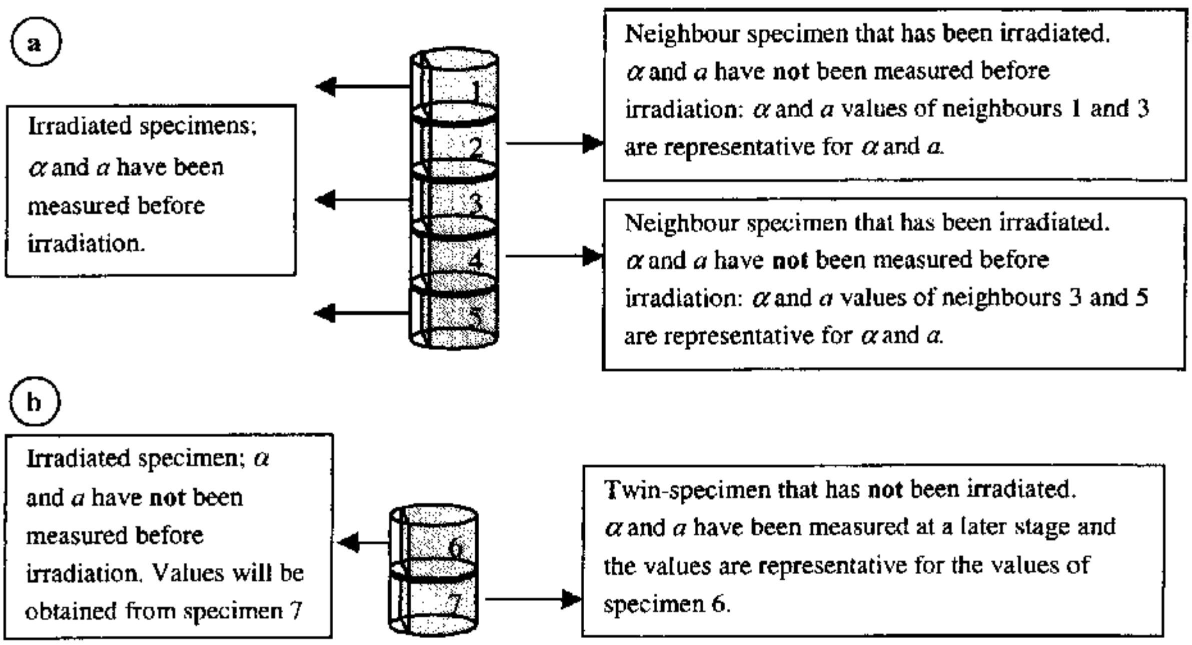

figure 3 a) Neighbouring specimens: reference α and a data of specimens 2 and 4 will be obtained from their neighbours that have been measured before irradiation. b) Twin specimens: reference α and a data of specimens 6 (that will be irradiated) will be obtained from the twin specimen 7 (that will not be irradiated).

The second variant is the twin specimen (see figure 3b). A twin specimen will be fabricated from each specimen that will be irradiated but not measured in advance A twin specimen is a specimen that originally was located adjacent to the irradiated specimen in the graphite block and that will not be irradiated. This twin specimen can be measured during the irradiation experiment of the other specimen. The α and a values will be used as reference values for the specimen that was not measured before irradiation.

To be clear:

- Above measures only apply for measurements of the coefficient of thermal expansion and coefficient of thermal diffusivity. All specimens that will be irradiated will be measured on mass, dimensions and Dynamic Young's modulus before the irradiation experiment.
- No coefficient of thermal diffusivity measurements will be performed on the 12 mm specimens due to size problems.

4 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.

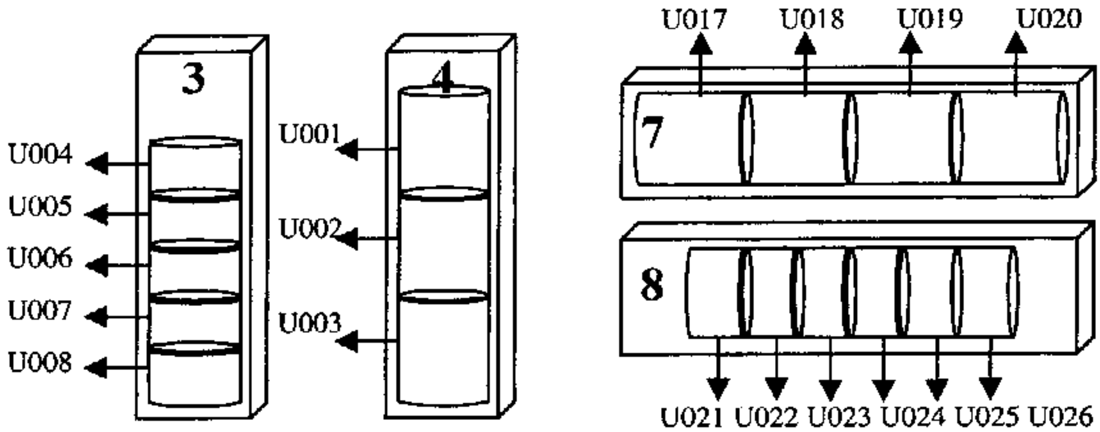

figure 4 Examples of the specimen procurement from the bars. Above bars are from the centre area of PCEA (see figure C1, Appendix C). Longitudinal lengths of bars 3 and 4 are in the *z*-direction, the longitudinal lengths of bars 7 and 8 are in the *xy*-direction. Specimens U001 t/m U003 have a length 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.

Tables D1 t/m D3 (Appendix D) show the preliminary specimen list of the irradiation experiment INNORGAPH. Some minor changes may be applied, depending on the fabrication of the last specimens and the results of the pre-irradiation testing, which is not finished at this report is written. The number of specimens will be the same. The position and orientation of the specimens in the graphite blocks is given by matching the number of the bars and the numbers in the cutting schemes in Appendix C .
The first specimens that will be selected from the minor grades (if there is space left in the rig) are given in table D4.

5 Conclusions

Five graphite grades will be irradiated in the INNOGRAPH experiment in the frame of the HTR-M1 project. The grades are obtained from Graftech, SGL-Carbon and Toyo Tanso. They cover a range of different microstructures because different combinations of raw materials and production processes are included. The raw materials are either pitch-coke or petroleum coke, the production processes are either extrusion or iso-moulding.

Large graphite blocks are delivered at NRG where the specimens are fabricated. The specimen shape is cylindrical with a flattened plane along the length of the specimens. This plane is used to retain the z-direction of the original graphite blocks. The diameter of the cylinders is 8 mm. The length is either 6 mm or 12 mm.

From each of the five major grades (PCEA, PCIB, NBG-10, NBG-25 and IG-110) 30 specimens will be put in INNOGRAPH. This means 15 specimens per main direction (z and xy). The specimens are procured from both the centre areas as well as the edge area of the graphite blocks. If there is space left in the INNOGRAPH rig some specimens may be added from the minor grades PPEA, NBG-20 and IG-430

To save time in the pre-irradiation testing not all specimens are tested by the time consuming expansion and diffusivity measurements. From the specimens that are not measured before irradiation there is either a neighbouring specimen or twin specimen that is measured. The results of this neighbour/ twin specimen are representative for the not-measured specimen.

Literature

[1] M.W. Davies, G.Haag, State of the art review of graphite materials and behaviour, HTR-M-02/6-D-3.1.37. NNC report C6463/TR/011.

[2] M.W. Davies, Report on selection of graphites and testing requirements, HTR-M1-02/11-D-2.1.9. NNC report C6657/TR/001.

appendix A Properties of the delivered graphites according graphite manufacturers.

table A1 Properties of the graphites from Graftech, according 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 A2 Properties of the graphites from SGL-Carbon, according 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		NBG-20	
Property	units	z	xy	z	xy	z	xy
Density	g/cm^3	1.81 / 1.79		1.815		1.78	
Real Density	g/cm^3	2.02 / 2.02		-		2.11	
Electrical Resistivity	μΩm	8.4 / 9.1	8.6 / 9.3	10.9	9.5	8.2	8.9
Young's Modulus	GPa	10.3 / 9.7	9.9 / 9.7	9.9	10.9	10.2	9.4
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	3.6	4.4
Thermal Conductivity (at RT)	W/mK	161 / 148	157 / 145	112	126	165	152
Flex Strength	MPa	30 / 24	27 / 27	44	48	30.2	29.2
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		16	
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		-		10	
Rm (average pore size)	μm	6 / 6		-		4.6	

table A3 Properties of the graphites from Toyo Tanso, according Toyo Tanso.

		IG-110		IG-430	
Property	Units	xy	z	xy	z
Density	g/cm^3	1.77		1.82	
Electrical Resistivity	μΩm	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 Impurites of the delivered graphites according graphite manufacturers.

table B1 Impurities of the graphites from Graftech, according to Graftech

	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 B2: Impurities of graphites from SGL-carbon, according SGL

	NBG-25		**NBG-10**	**NBG-20**
Ag	< 0,01	B	0.4	1
Al	0.06	Si	45	3
Au	< 0,06	Fe	3	9
B	< 0,03	Ca	5	8
Ba	0.001	V	0.2	8
Be	< 0,001	Ni	0.2	1
Bi	< 0,03	Ti	0.4	2
Ca	0.06	W	0.2	
Cd	<0,005	Co	<0,1	<0,1
Ce	<0,02	Ag		
Cl	7	Al	<0,1	10
Co	<0,005	Ba	0.3	0.7
Cr	<0,005	Be	-	<0,1
Cu	0.008	Bi		
Dy	<0,005	Cd	<0,1	-
Eu	<0,005	Cr	<0,1	0.3
Fe	0.09	Cu	<0,1	<0,1
Ga	< 0,02	K		
Gd	< 0,005	Li	<0,1	-
Ge	< 0,03	Mg	0.5	
Hf	< 0,01	Mn	<0,1	<0,1
Hg	< 0,05	Mo	0.1	<0,1
In	< 0,03	Na	0.2	-
K	< 0,01	P	0.6	2
La	< 0,005	Pb	<0,1	<0,1
Li	< 0,005	S		
Mg	0.01	Sn		
Mn	< 0,002	Sr	<0,1	0.4
Mo	< 0,02	Zn	<0,1	5

	NBG-25			
Na	0.01			
Nb	< 0,01			
Nd	< 0,01			
Ni	0.2			
Pb	< 0,06			
Pr	< 0,05			
Re	< 0,01			
Rh	< 0,01			
Ru	< 0,01			
S	0.6			
Sb	< 0,05			
Sc	< 0,005			
Se	< 0,01			
Si	0.3			
Sm	< 0,005			
Sn	< 0,02			
Sr	< 0,005			
Ta	< 0,01			
Te	< 0,03			
Th	< 0,01			
Ti	< 0,005			
Tl	< 0,08			
U	< 0,02			
V	< 0,005			
W	0.01			
Y	< 0,05			
Zn	0.01			
Zr	< 0,03			

table B3 Impurities of graphites from Toyo Tanso, according Toyo Tanso.

	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.

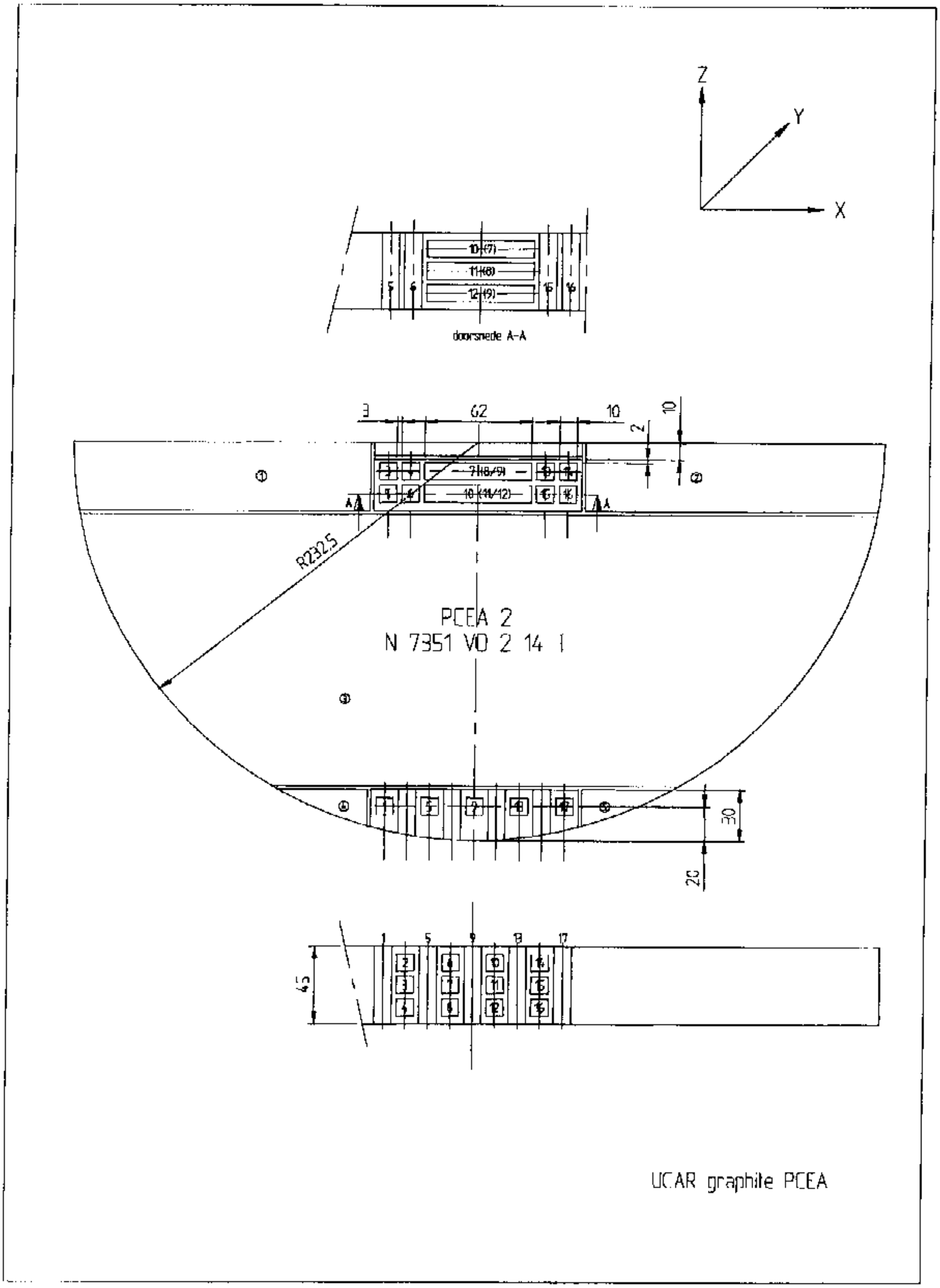

figure C1: Cutting scheme of PCEA graphite block.

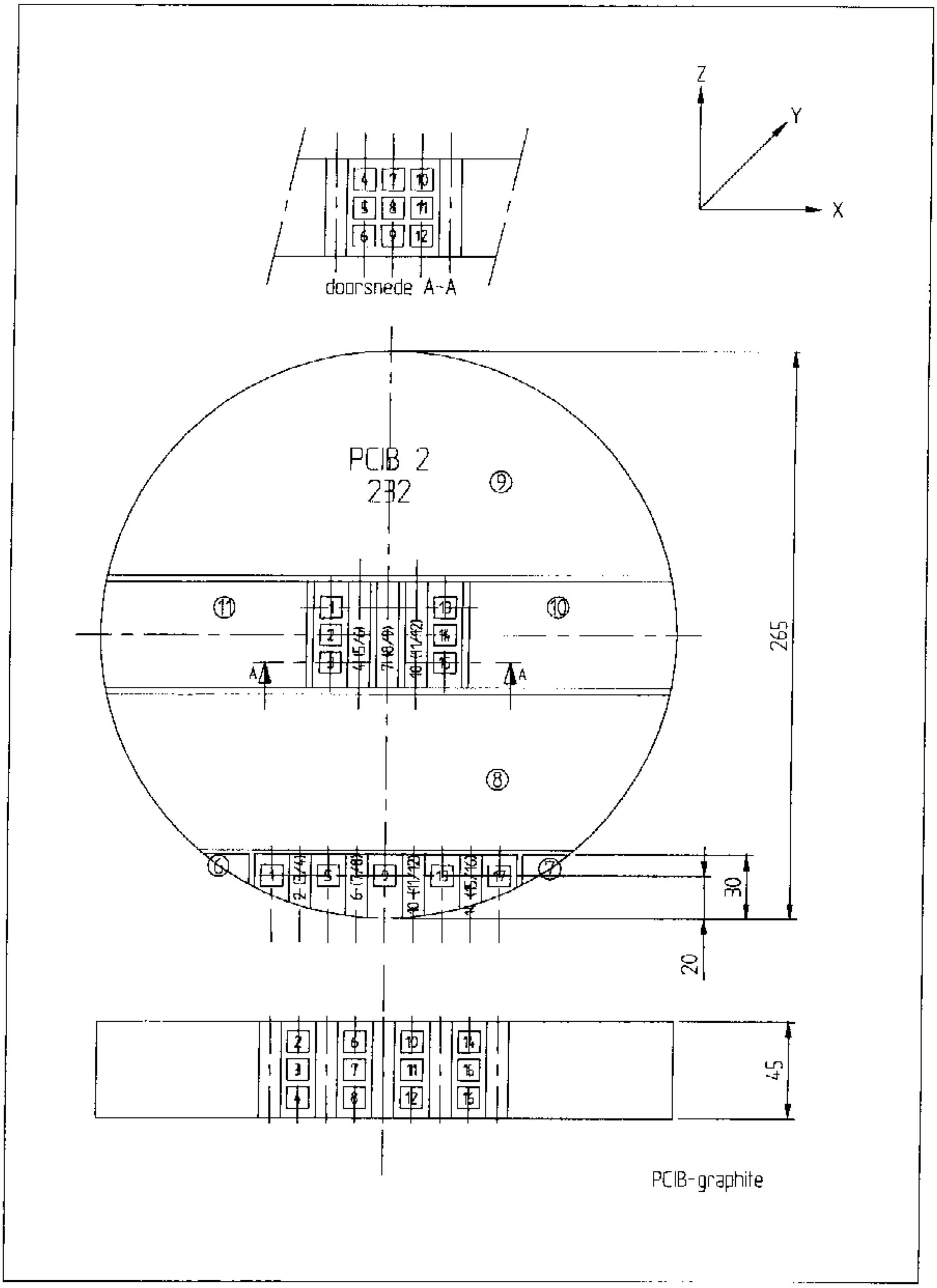

figure C2: Cutting scheme of PCIB graphite block.

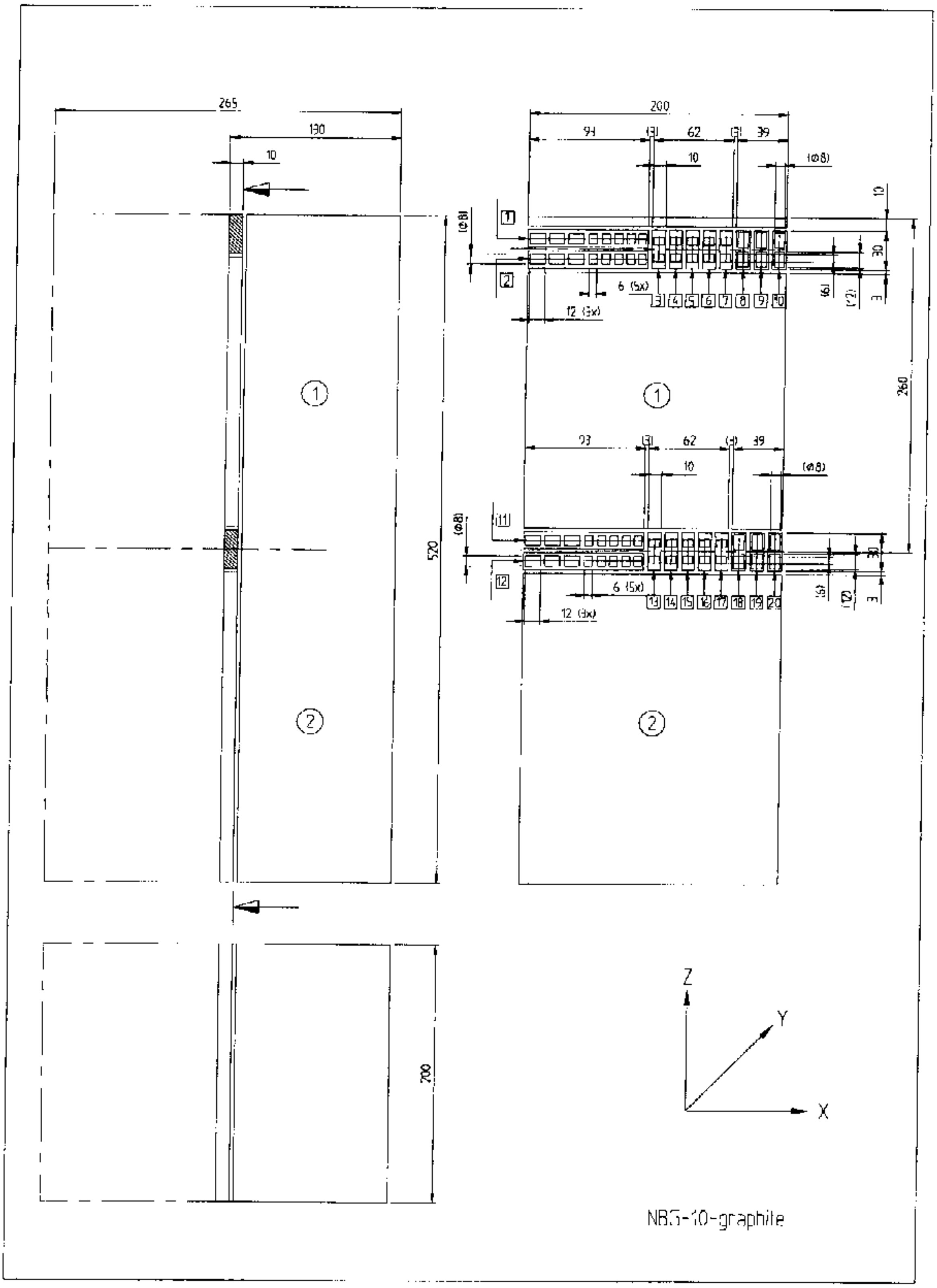

figure C3: Cutting scheme of NBG-10 graphite block.

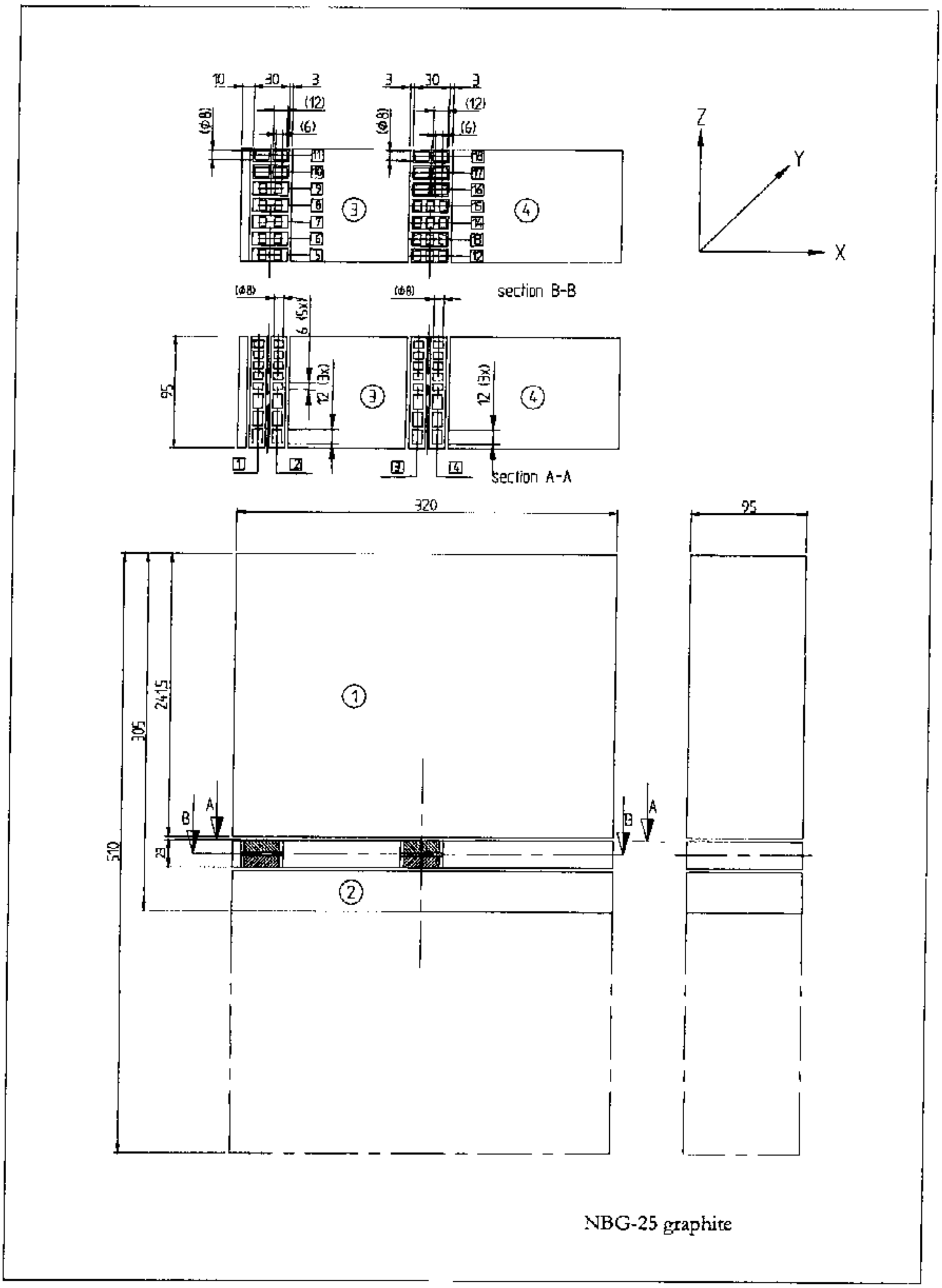

figure C4: Cutting scheme of NBG-25 graphite block.

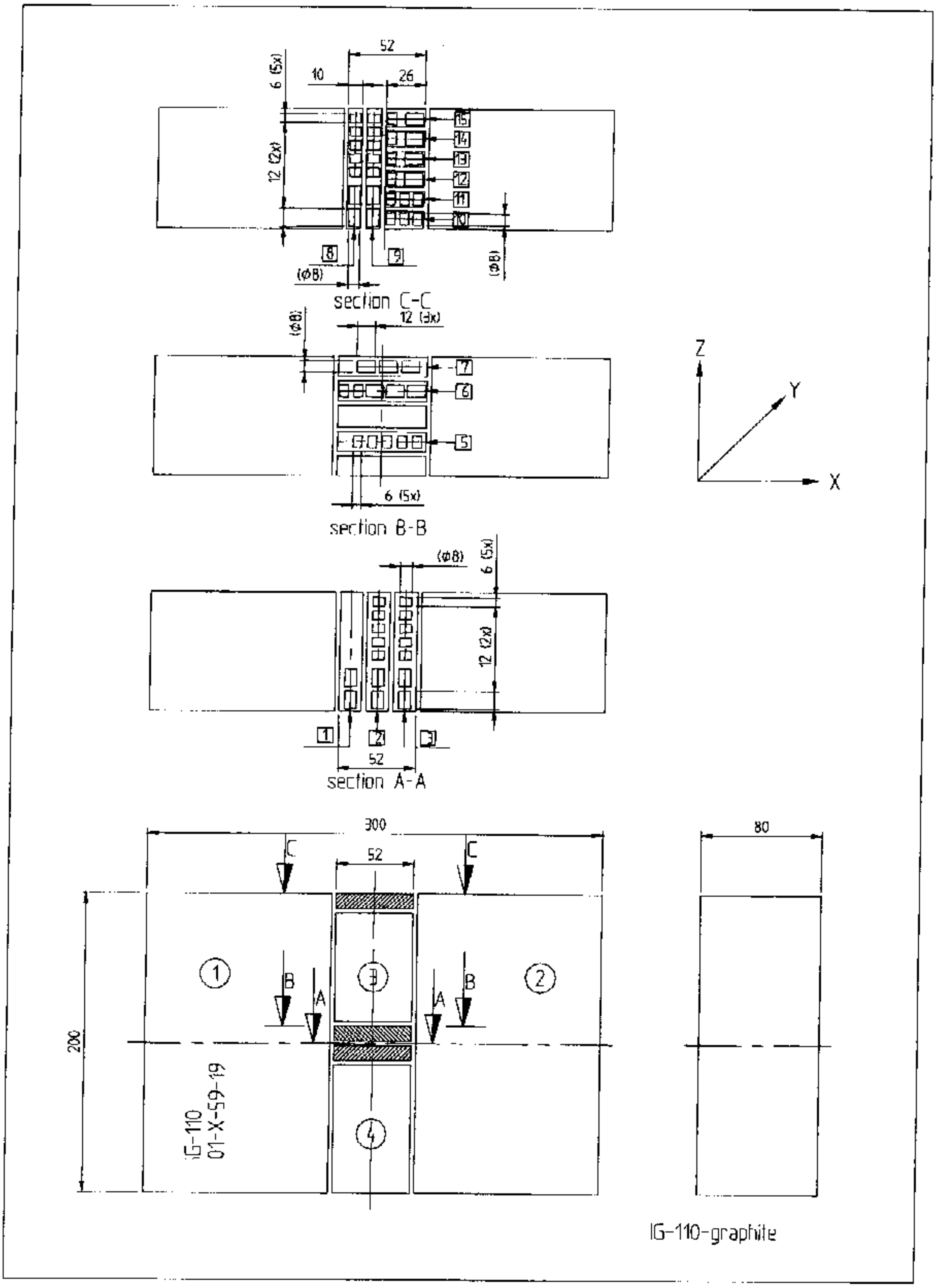

figure C5: Cutting scheme of IG-110 graphite block.

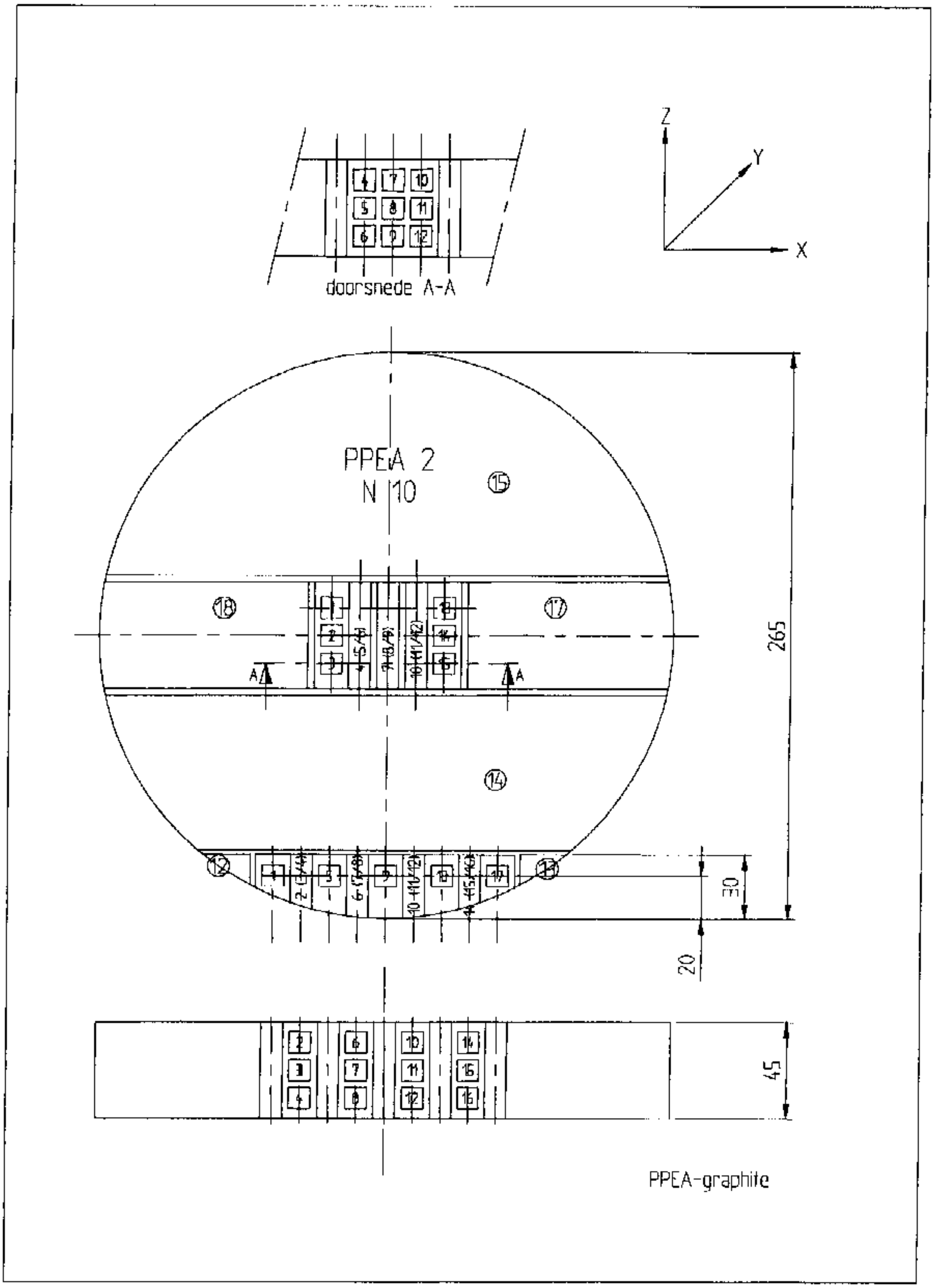

figure C6: Cutting scheme of PPEA graphite block.

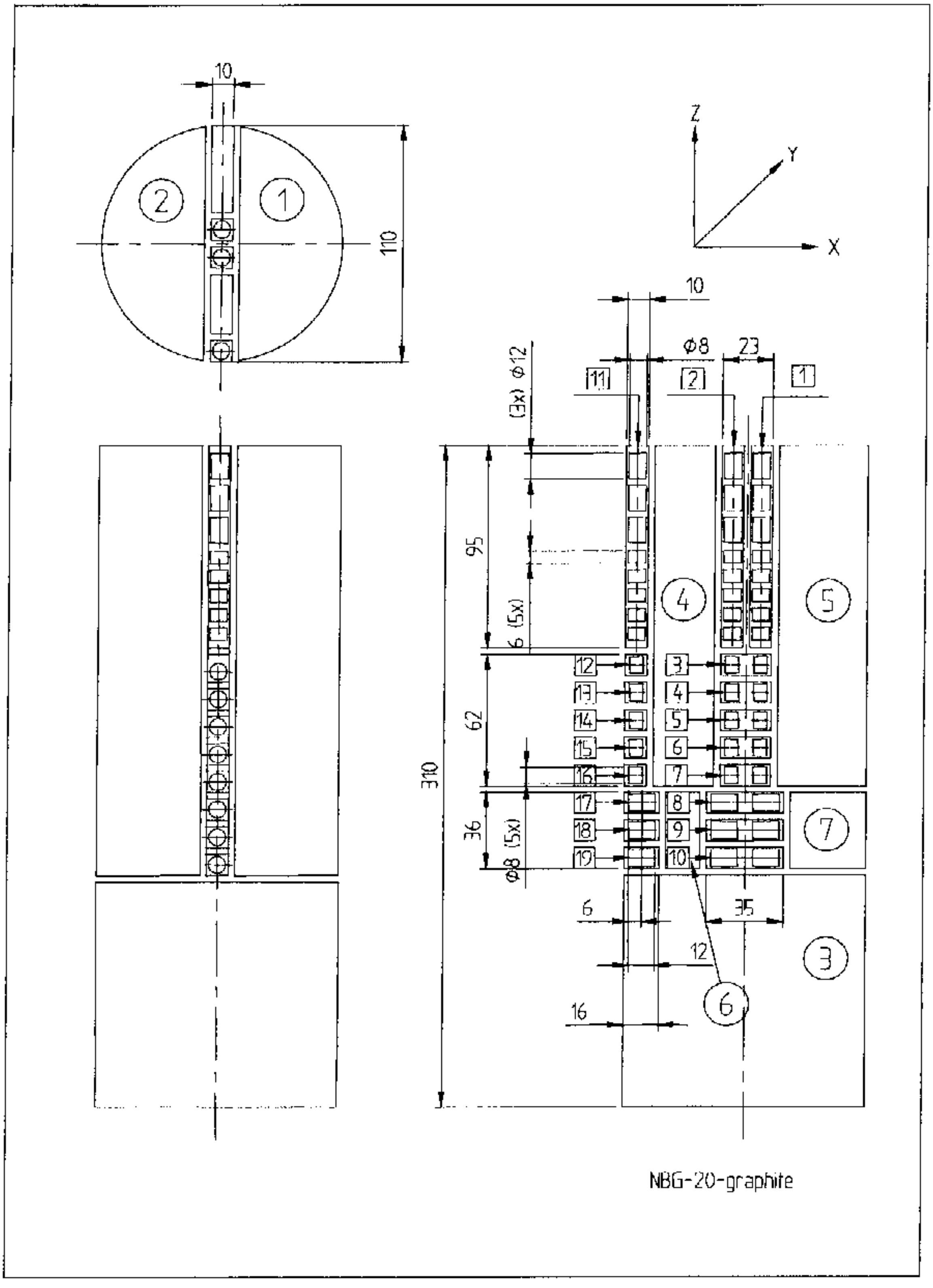

figure C7: Cutting scheme of NBG-20 graphite block.

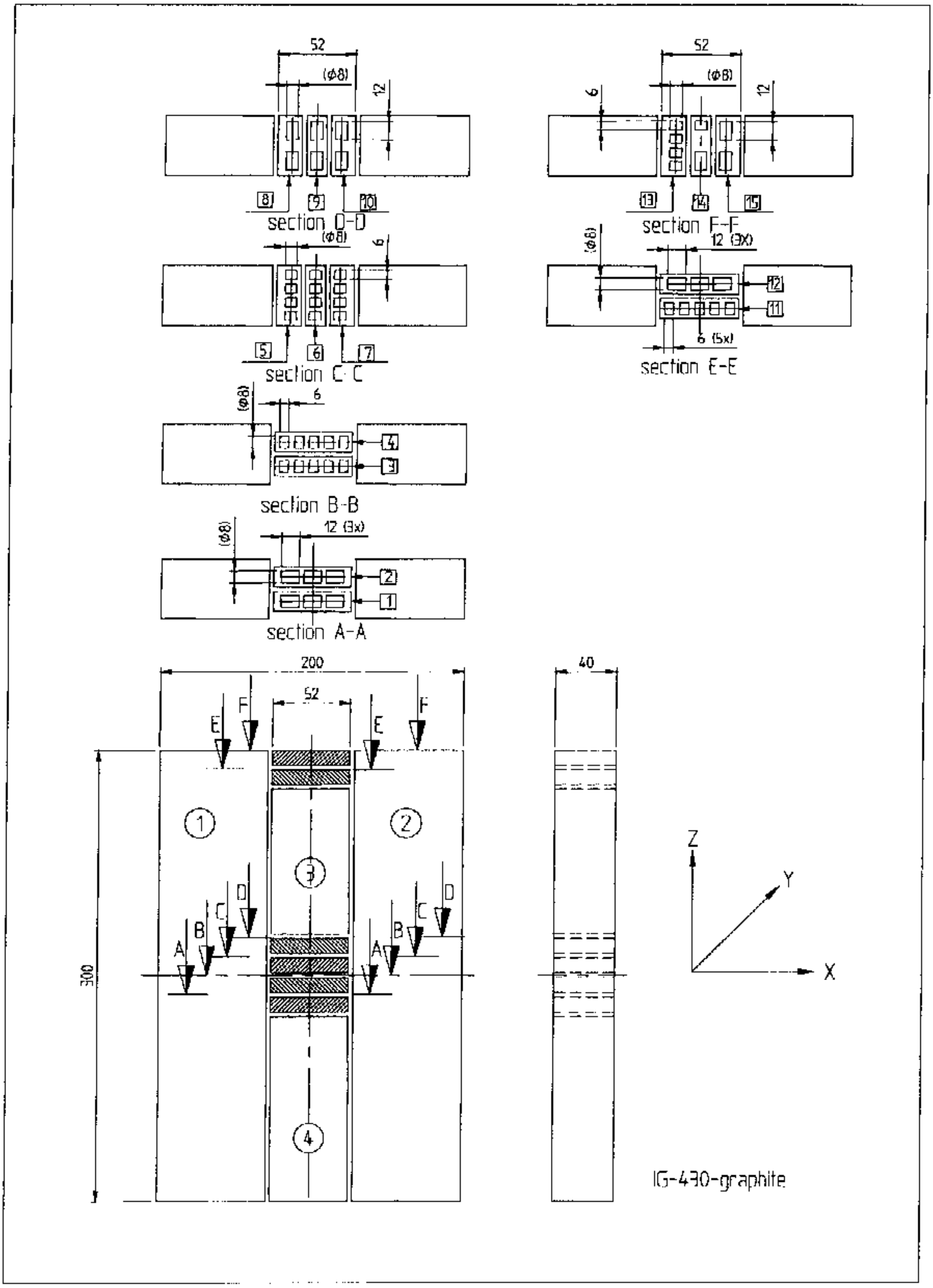

figure C8: Cutting scheme of IG-430 graphite block.

appendix D Preliminary list of specimens for the irradiation experiment INNOGRAPH.

table D1 Preliminary list of specimens from PCEA and PCIB (Graftech)

Specimens	Number	Length (mm)	Grade	Orientation	Location	Bar number
U004 - U008	5	6	PCEA	z	Centre	4
U001, U003	2	12	PCEA	z	Centre	3
U016	1	12	PCEA	z	Centre	6
U021 - U025	5	6	PCEA	xy	Centre	8
U017, U019	2	12	PCEA	xy	Centre	7
U037	1	12	PCEA	xy	Centre	11
U069 - U073	5	6	PCEA	z	Edge	5
U063, U065	2	12	PCEA	z	Edge	1
U080 - U082	3	6	PCEA	xy	Edge	8
U077, U079	2	6	PCEA	xy	Edge	7
U066	1	12	PCEA	xy	Edge	2
U068	1	12	PCEA	xy	Edge	4
U112 - U115	4	6	PCIB	z	Centre	2
U164	1	6	PCIB	z	Centre	13
U108	1	12	PCIB	z	Centre	1
U116, U118	2	12	PCIB	z	Centre	3
U123 - U127	5	6	PCIB	xy	Centre	5
U119, U121	2	12	PCIB	xy	Centre	4
U130	1	12	PCIB	xy	Centre	6
U196 - U200	5	6	PCIB	z	Edge	9
U176, U178	2	12	PCIB	z	Edge	1
U190 - 192	3	6	PCIB	xy	Edge	7
U193, U195	2	6	PCIB	xy	Edge	8
U179	1	12	PCIB	xy	Edge	2
U181	1	12	PCIB	xy	Edge	4

table D2 Preliminary list of specimens from NBG-10 and NBG-12 (SGL-Carbon)

Specimens	Number	Length (mm)	Grade	Orientation	Location	Bar number
S030, S032, S034	3	6	NGB-10	z	Centre	11
S031, S033	2	6	NBG-10	z	Centre	12
S024, S028	2	12	NBG-10	z	Centre	11
S029	1	12	NBG-10	z	Centre	12
S040, S041	2	6	NBG-10	xy	Centre	13
S042, S043	2	6	NBG-10	xy	Centre	14
S044	1	6	NBG-10	xy	Centre	15
S050	1	12	NBG-10	xy	Centre	18
S052	1	12	NBG-10	xy	Centre	19
S054	1	12	NBG-10	xy	Centre	20
S063, S065, S067, S069, S071	5	6	NGB-10	z	Edge	2
S057, S061	2	12	NGB-10	z	Edge	2
S072, S073	2	6	NBG-10	xy	Edge	3
S074, S075	2	6	NBG-10	xy	Edge	4
S076	1	6	NBG-10	xy	Edge	5
S084	1	12	NBG-10	xy	Edge	9
S086	1	12	NBG-10	xy	Edge	10
S094, S096, S098	3	6	NBG-25	z	Centre	3
S095, S097	2	6	NBG-25	z	Centre	4
S088, S092	2	12	NBG-25	z	Centre	3
S093	1	12	NBG-25	z	Centre	4
S110-S112	3	6	NBG-25	xy	Centre	14
S113, S114	2	6	NBG-25	xy	Centre	15
S116	1	12	NBG-25	xy	Centre	16
S118	1	12	NBG-25	xy	Centre	17
S120	1	12	NBG-25	xy	Centre	18
S128, S130, S132, S134, S135	5	6	NBG-25	z	Edge	1
S122, S126	2	12	NBG-25	z	Edge	1
S138, S139	2	6	NBG-25	xy	Edge	5
S140,S141	2	6	NBG-25	xy	Edge	6
S142	1	6	NBG-25	xy	Edge	7
S148	1	12	NBG-25	xy	Edge	10
S150	1	12	NBG-25	xy	Edge	11

table D3 Preliminary list of specimens from IG-110 (Toyo Tanso)

Specimens	Number	Length (mm)	Grade	Orientation	Location	Bar number
T007, T009, T011	3	6	IG-110	z	Centre	2
T008, T010	2	6	IG-110	z	Centre	3
T004	1	12	IG-110	z	Centre	1
T005	1	12	IG-110	z	Centre	2
T006	1	12	IG-110	z	Centre	3
T022 – T026	5	6	IG-110	xy	Centre	5
T027, T029	2	12	IG-110	xy	Centre	6
T031	1	12	IG-110	xy	Centre	7
T037, T039, T041, T043, T045	5	6	IG-110	z	Edge	8
T035	1	12	IG-110	z	Edge	8
T036	1	12	IG-110	z	Edge	9
T047- T049	3	6	IG-110	xy	Edge	10
T050,T051	2	6	IG-110	xy	Edge	11
T058	1	12	IG-110	xy	Edge	13
T059	1	12	IG-110	xy	Edge	14

table D4 Preliminary list of specimens from the minor grades PPEA, NBG-20 and IG-430 that may be included in the irradiation experiment.

Specimens	Number	Length (mm)	Grade	Orientation	Location	Bar number
U276 – U280	5	6	PPEA	z	Centre	13
U236 – U240	5	6	PPEA	xy	Centre	5
S158, S160, S162, S164, S166	5	6	NBG-20	z	Centre	1
S168, S169	2	6	NBG-20	xy	Centre	3
S170, S171	2	6	NBG-20	xy	Centre	4
S172	1	6	NBG-20	xy	Centre	5
T067, T070, T073, T076	4	6	IG-430	z	Centre	5
T071	1	6	IG-430	z	Centre	6
T079 – T083	5	6	IG-430	xy	Centre	3