

Title	Vacuum-Compatible X-Ray Crystal Assemblies with Multi-Axis Precision Alignment Stages and accessories
Subtitle	PART-A(II): Scope of Supply, Scope of Work and Technical Specifications

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1 Introduction

This is a proposal for procuring curved crystals with multi- axis precision alignment stages required for X-ray crystal spectrometer experiments at ITER-India, IPR, India. The document describes the complete technical and application details to the manufacturers or suppliers for quoting all the relevant products, complying with ITER-India requirements.

The Institute for Plasma Research (IPR) is a leading research institution dedicated to advancing plasma science and technology in India. Within this framework, ITER-India serves as the Indian domestic agency (IN-DA) for ITER, focusing on research and developments to provide in-kind systems/components to the International Thermonuclear Experimental Reactor (ITER). As a part of these contributions, ITER-India is designing, developing, two X-ray spectrometers: Broadband X-ray Crystal Spectrometer (XRCS-Survey) and a High-resolution X-ray Crystal Spectrometer (XRCS-Edge) for ITER. These spectrometers detect and estimate impurity in-flux, impurity concentration and plasma ion temperature of ITER plasma, respectively.

The XRCS-Survey spectrometer has a set of X-ray crystals and detector assemblies that are operated inside the high vacuum (10^{-6} mbar or better). The X-rays, in the range of 500eV to 1200 eV, from plasma are dispersed using crystals. The proposed crystal assemblies are intended to be used in prototype developmental activities conducted at the ITER-India laboratory.

2 Scope of Supply

Table 1: List of items to be delivered

Sr No #	Item Name	Unit	Quantity
1.	Cubic shaped X-ray Crystals with substrates	Set	4
2.	X-ray crystal integration mounting, along with accessories	set	4
3.	5 Axis vacuum compatible precision motorized Alignment stage	Set	3
4.	All required accessories such as controllers, feedthroughs and cables to operate the stages.		As per requirement

3 Scope of Work

The scope of work includes manufacturing of four different types of cubic curved crystals according to the curvature specifications along with a specific integration mounts and a vacuum compatible, compact multi-axis alignment stage to perform X-ray diffraction experiments.

4 Technical Specifications

ITER-India intends to procure crystal assemblies integrated onto a multi-axis vacuum compatible alignment stages having 5 degrees of freedom. The technical specifications which will be evaluated for performance are given in Table 2, Table 3,& Table 4.

Table 2: Technical Specification of the Crystals

S.No.	Parameters	Crystal-1	Crystal-2	Crystal-3	Crystal-4
1	Quantity	1	1	1	1
2	Crystal Material	Pentaerythritol (PET)	Pentaerythritol (PET)	Silicon	Silicon
3	Crystal cut [h k l]	[002]	[002]	[422]	[422]
4	Inter lattice plane distance (2d) Å	8.74	8.74	2.22	2.22
5	Projected length (mm)	43	43	60	60
6	Crystal height (mm)	16	16	14	14

7	Crystal surface parallelism	One λ or better at ~632 nm	One λ or better at ~632 nm	One λ or better at ~632 nm	One λ or better at ~632 nm
8	Vacuum Compatibility (Pa)	$\leq 10^{-6}$	$\leq 10^{-6}$	$\leq 10^{-6}$	$\leq 10^{-6}$
	Leak Rate (Pa.m ³ /sec)	10^{-9}	10^{-9}	10^{-9}	10^{-9}
9	Crystal Shape (profile)	Cubic	Cubic	Cubic	Cubic

Table 3: Technical Specification of the Substrate for crystal cubic profile

Parameter	Specification	Remarks
Substrate Material	SS 316	
Substrate length and height (mm)	Compatible with the required crystal dimensions in Table.2	The substrate geometry details are given in Appendix-1
Thickness of substrate (mm)	As defined in the Drawing	details are given in Appendix-1
Front surface	Cubic shape with a variable radius of curvature generated based on the given 3 rd ordered polynomial equation.	Appendix -1 for polynomial coefficients
Crystal orientation	Parallel to center of substrate ± 1 degree	
Contacting voids	< 5% of crystal area	
Crystal to substrate attachment	Using vacuum compatible glue	The leak rate of crystal substrate glue has to comply with the achievable vacuum compatibility (Sr.no.8, Table.2)

Table 4: Technical Specification of the Crystal assembly with 5 Axis motorized stage

A. 5 Axis Motorized Stage		
Quantity	03	
Parameters	Linear Stage	Rotational Stage
Absolute positioning accuracy	2-3 μ m	0.15 ⁰ -0.25 ⁰
Repeatability	$\pm 2 \mu$ m	$\pm 0.1^0$
Travel range (X,Y & Z each direction with respect to central position)	± 12 mm	$\pm 15^0$ in Y & Z direction
Resolution	1 - 2 μ m	0.01 ⁰ - 0.02 ⁰
Limit switches	Optical Limit switch at both ends of travel	Optical sensor for precise reference positioning
Translation Direction	X,Y and Z	Rotation about Y & Z direction (see figure 6 Appendix-II for direction notation)
Vacuum Compatibility: High vacuum (Pa) Leak Rate (Pa.m ³ /sec)	$\leq 10^{-6}$ $\leq 10^{-9}$	
Material	SS 304	
Finish	Without Anodizing (Desirable for Vacuum)	
Motor type	Stepper motor /Piezo Motor	
5 Axis Stage motors configuration & control	5-Axis Motion Controller system with it's accessories (vacuum feedthroughs, in-vacuum & in-air cables etc)	
Interface	Ethernet	
Controller Software	PC-based GUI software Compatible with latest Windows version	
Overall dimension Width x Depth x Height (mm)	$\leq 250 \times 250 \times 310$ See figure 6 Appendix-II (reduction in width is preferable)	
Crystal with substrate weight load on stage	~ 0.5 kg	
Desirable Software features	To configure & control the multi axis stage with the GUI software features like:	

	Programmable with positional memory, Over-travel, Emergency stop function Real-time position display, Absolute and incremental movement options, Preset position storage and recall, Axis synchronization and sequencing Optional scripting interface (Python, LabVIEW)
Crystal integration onto the multi-axis stage	Using mounting rods and customized platforms on the multi-axis alignment stage for integrating and aligning the crystal assembly.

5 Software required

- Motorized stage control and operation software required for alignment stage configuration as per requirements

6 Accessories/ Spares

- All standard accessories required for mounting the crystals onto the alignment stages and for the operation of the motorized stage, need to be included in the supply.
- All cables & connectors for motorized stage controller, mounts, vacuum feedthrough for cable connections.
- Motorized Stage controller Power supplies compatible with power rating of AC 230V, 50 Hz.

7 Acceptance tests: Pre-dispatch/FAT

Before dispatch of material to ITER-India, ITER-India personnel will conduct a pre-dispatch inspection for inspection and testing of crystal assemblies onto the multi-axis alignment stages. The compliance with Table 5 will be verified during PDI. If found satisfactory, ITER-India will send the dispatch clearance certificate for dispatch of the material.

Table 5: Factory acceptance tests (FAT)

Sr. No.	Parameter	Test/certificate/Data
1	Photographs of the manufactured crystals	Individual crystal assembly photographs
2	Conformity certificates-certifying the crystal material , crystal orientation and outgassing rate of the glue.	Certificate from OEM
3	Crystal assembly dimensions	As built Drawings

4	Manufacturing data of the substrate cubic profile	Data file containing list of measured data points (Excel file)
5	Multi-axis alignment stages: Test parameters : (Travel range, Resolution, Repeatability)	These parameters need to be demonstrated using Dial gauge & auto collimator or other suitable measuring devices for all 3 stages.
6	Integrated testing of Crystal assembly mounted onto the alignment stages.	The integrated crystal assemblies (4), mounted on precision alignment stages, shall be demonstrated for full five-axis motion—X, Y, Z linear translations and θ , ϕ angular rotations—in accordance with ITER-India specifications. The motion shall be executed and controlled through the multi axis stage control software.

8 Site installation and final/ Site Acceptance Test (SAT) at ITER-India site

At ITER-India lab, installation, testing and demonstration of system's performance as per tests described in Table 6 must be carried out by the supplier. After successful commissioning at ITER-India, a final acceptance will be given only when it complies with all the technical specifications.

Table 6: Site acceptance test (SAT)

Sr. No.	Parameter	Test/certificate/Data
1	Multi-axis alignment stages: Test parameters : Travel range Resolution Repeatability	The tests for Travel range, resolution and Repeatability will be conducted for compliance with FAT results These parameters will be

		demonstrated using dial gauge & auto collimator or other suitable measuring devices.
2	Integrated testing of Crystal assembly mounted onto the alignment stages.	All the tests for demonstrating performance of the integrated crystal assembly, mounted on precision alignment stages, shall be demonstrated for full five-axis motion—X, Y, Z linear translations and θ , ϕ angular rotations—in accordance with ITER-India specifications using designated stage control software.

9 Document deliverables

- Multi axis stage Operation & maintenance manual, technical drawings of crystals, stages, the crystal substrate glue (adhesive) data sheet, Crystal & Substrate material certificate. Test Report of integrated Alignment Stage & Crystals with the Procedure for mounting and dismounting of crystal on motorized stage.
- All documentation shall be in English language only.

10 Input drawings / documents

Drawings of all crystals & 5 -axis stages needs to be supplied

11 Technical Compliance Format

The supplier must fill, sign, and stamp the below table as part of compliance to the requirements. As an evidence of offered specifications the supplier shall submit appropriate documentary evidences such as test reports, specify the values wherever applicable or confirm the same.

Table 7: Technical Compliance table for individual crystal

S.No.	Parameters	Crystal-1	Crystal-2	Crystal-3	Crystal-4	Supplier remarks(individual Crystal)
1	Quantity	1	1	1	1	
2	Crystal Material	Pentaerythritol (PET)	Pentaerythritol (PET)	Silicon	Silicon	
3	Crystal cut [h k l]	[002]	[002]	[422]	[422]	
4	Inter lattice plane distance (2d) Å	8.74	8.74	2.22	2.22	
5	Projected length (mm)	43	43	60	60	
6	Crystal height (mm)	16	16	14	14	
7	Crystal surface parallelism	One λ or better at ~632 nm	One λ or better at ~632 nm	One λ or better at ~632 nm	One λ or better at ~632 nm	
8	Vacuum Compatibility (Pa) Leak Rate (Pa.m ³ /sec)	$\leq 10^{-6}$ 10^{-9}	$\leq 10^{-6}$ 10^{-9}	$\leq 10^{-6}$ 10^{-9}	$\leq 10^{-6}$ 10^{-9}	
9	Crystal Shape (profile)	Cubic	Cubic	Cubic	Cubic	

Table 8 Technical Specification of the Substrate for crystal profile

Parameter	Specification	Supplier remarks
Substrate Material	SS 316	
Substrate length and height (mm)	Compatible with the required crystal dimensions in Table.2	

Thickness of substrate (mm)	As defined in the Drawing	
Front surface	Cubic shape with a variable radius of curvature generated based on the given 3 rd ordered polynomial equation.	
Crystal orientation	Parallel to center of substrate ± 1 degree	
Contacting voids	< 5% of crystal area	
Crystal to substrate attachment	Using vacuum compatible glue	

Table 9: Technical Specification of the Crystal assembly with 5 Axis motorized stage

A. 5 Axis Motorized Stage			Supplier remarks
Quantity	03		
Parameters	Linear Stage	Rotational Stage	
Absolute positioning accuracy	2-3 μ m	0.15 ⁰ -0.25 ⁰	
Repeatability	$\pm 2 \mu$ m	$\pm 0.1^0$	
Travel range (X,Y & Z each direction with respect to central position)	± 12 mm	$\pm 15^0$ in Y & Z direction	
Resolution	1 - 2 μ m	0.01 ⁰ - 0.02 ⁰	
Limit switches	Optical Limit switch at both ends of travel	Optical sensor for precise reference positioning	
Translation Direction	X,Y and Z	Rotation about Y& Z direction (see Figure 6 ,Appendix-II for direction notation)	
Vacuum Compatibility: High vacuum (Pa) Leak Rate (Pa.m ³ /sec)	$\leq 10^{-6}$ $\leq 10^{-9}$		
Material	SS 304		

Finish	Without Anodizing (Desirable for Vacuum)	
Motor type	Stepper motor /Piezo Motor	
5 Axis Stage motors configuration & control	5-Axis Motion Controller system with it's accessories (feedthrough for vacuum chamber mounting and cables etc)	
Interface	Ethernet	
Controller Software	PC-based GUI software Compatible with latest Windows version	
Overall dimension Width x Depth x Height (mm)	$\leq 250 \times 250 \times 310$ See Appendix-II Figure6 (Reduction in width is preferable)	
Crystal with substrate weight load on stage	~ 0.5kg	
Desirable Software features	<p>To configure & control the multi axis stage with the GUI software features like:</p> <p>Programmable with positional memory, Over-travel, Emergency stop function Real-time position display, Absolute and incremental movement options, Preset position storage and recall, Axis synchronization and sequencing Optional scripting interface (Python, LabVIEW)</p>	
Crystal integration onto the multi-axis stage	Using mounting rods and customized platforms on the multi-axis alignment stage for integrating and aligning the crystal assembly.	

12 Appendix-I: Technical details of Cubic Crystals

The details of the crystals and their profile generation parameters are defined in Table 10 & Table 11. The cubic profile needs to be generated based on the equation and the corresponding start & end points along with fitting coefficients. Typical representation of the cubic profile is shown in Figure 1.

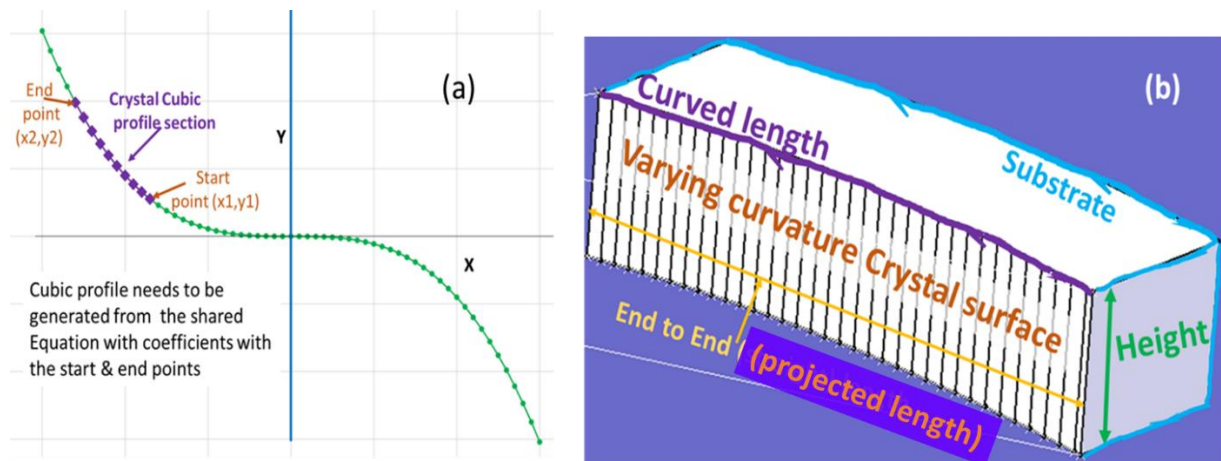


Figure 1: (a) Typical cubic curve to be generated from cubic equation (b) 3D model of Crystal

Table 10: Technical specification of PET crystals

S.No.	Parameters	Crystal-1 (C1)	Crystal-2 (C2)	Remarks
1	Quantity	1	1	
2	Crystal Material	PET	PET	
3	Effective crystal length (mm)	67.81	49.52	$\leq 2\%$ variation is acceptable
4	Cubic Equation for crystal $Y = ax^3 + bx^2 + cx + d$	$a = 3.2852e-05$ $b = 0.0087$ $c = 0.7812$ $d = 0$	$a = 1.5387e-05$ $b = 0.0041$ $c = 0.3659$ $d = 0$	Cubic shaped crystals of different lengths, The shape need to be manufactured as per these technical details.
5	Effective Crystal dimensions X range (mm) Y range(mm)	[0, 43] [0, 52.43]	[0, 43] [0, 24.56]	Usable crystal area
6	Manufacturing dimensions of Substrate X range (mm) Y range(mm)	[-1, 44] [-0.77, 54.16]	[-1, 44] [-0.36, 25.37]	This takes care of masking for keeping the margin for clear aperture and the mounts with tolerances
7	Effective substrate length (mm)	71.01	51.84	

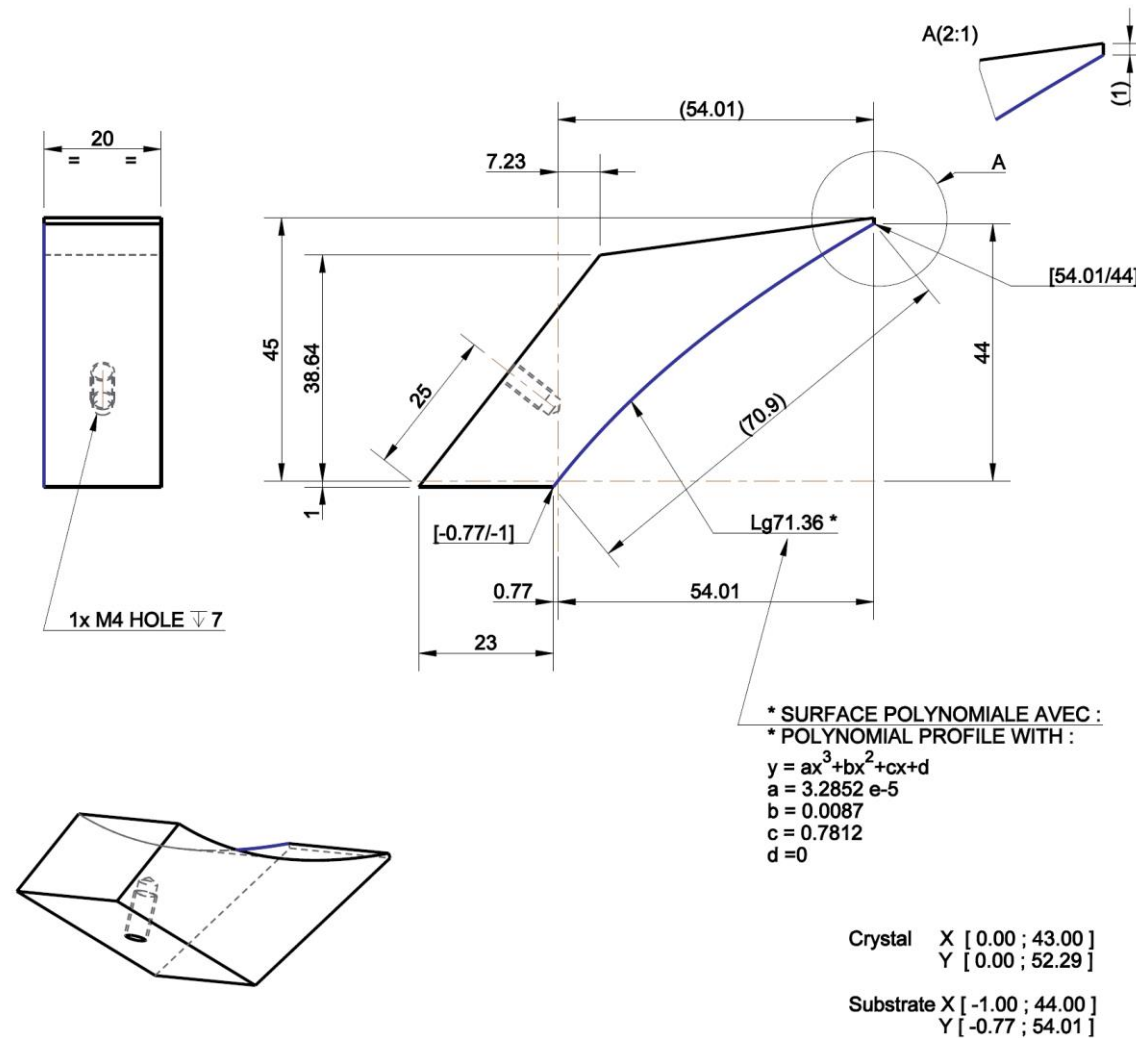


Figure 2: Schematic Drawing of PET Crystal-1, the supplier shall generate required engineering drawings as per specifications given in Table 10

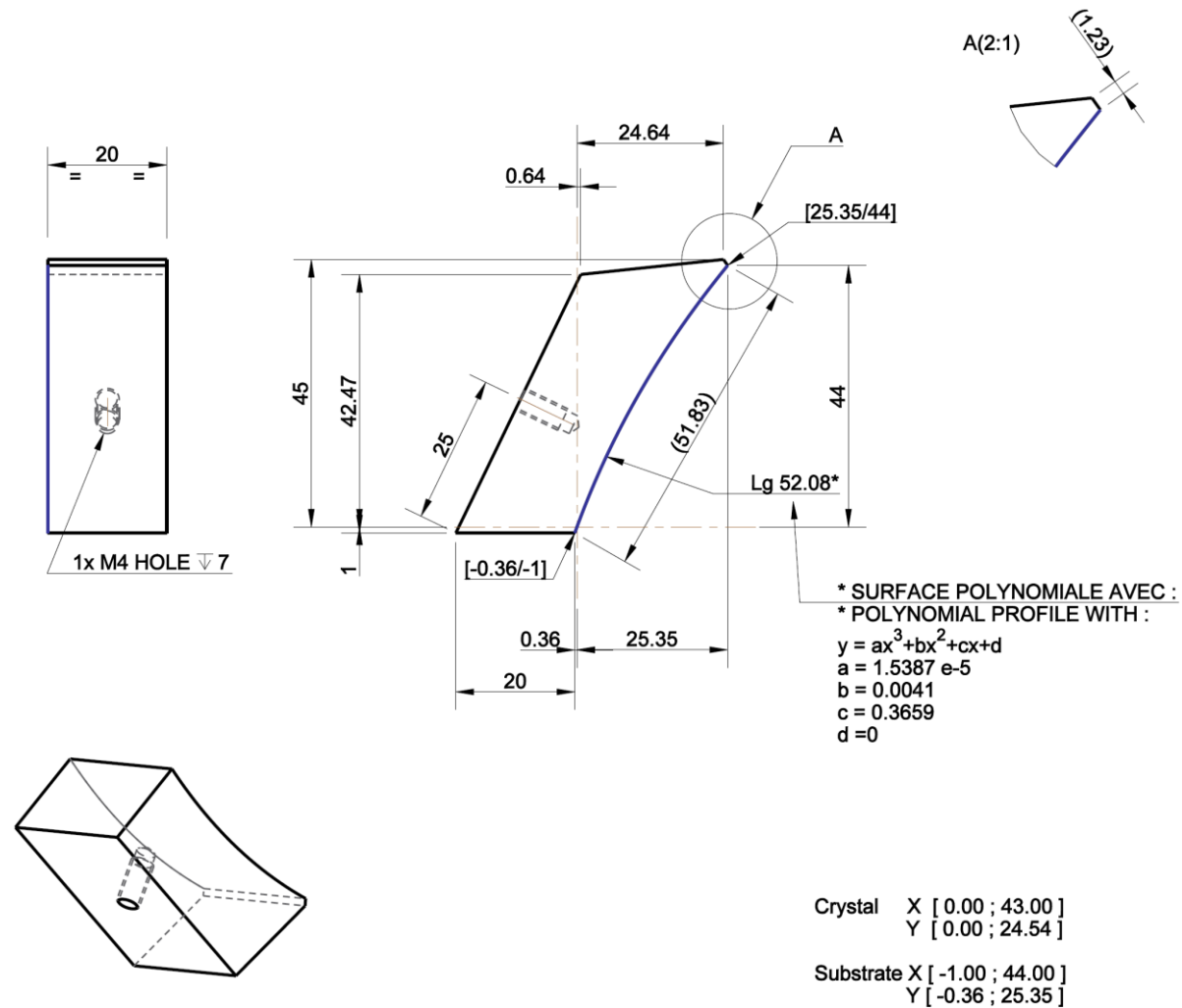


Figure 3: Schematic Drawing of PET Crystal-2, the supplier shall generate required engineering drawings as per specifications given in Table 10

Table 11 Technical details of Si (422) crystal

S.No.	Parameters	Crystal-3(C3)	Crystal-4(C4)	Remarks
1	Quantity	1	1	
2	Crystal Material	Si(422)	Si(422)	
3	Cubic Equation for crystal profile generation $Y = ax^3 + bx^2 + cx + d$	$a = 2.1486e-05$ $b = 0.0078$ $c = 0.9656$ $d = 0$	$a = 1.0375e-05$ $b = 0.0038$ $c = 0.4663$ $d = 0.0$	Cubic shaped crystals of different lengths, The shape need to be manufactured as per the technical details.
4	Effective Crystal X range (mm) Y range(mm)	 [0, 60] [0, 90.99]	 [0, 60] [0, 43.93]	Usable crystal area
5	Effective crystal length (mm)	108.99	74.37	$\leq 2\%$ variation is acceptable
6	Manufacturing dimensions of Substrate X range (mm) Y range(mm)	 [-1, 61] [-0.96, 93.14]	 [-1, 61] [-0.46 44.98]	This takes care of masking for keeping the margin for clear aperture and the mounts with tolerances
7	Effective substrate length (mm)	112.69	76.87	

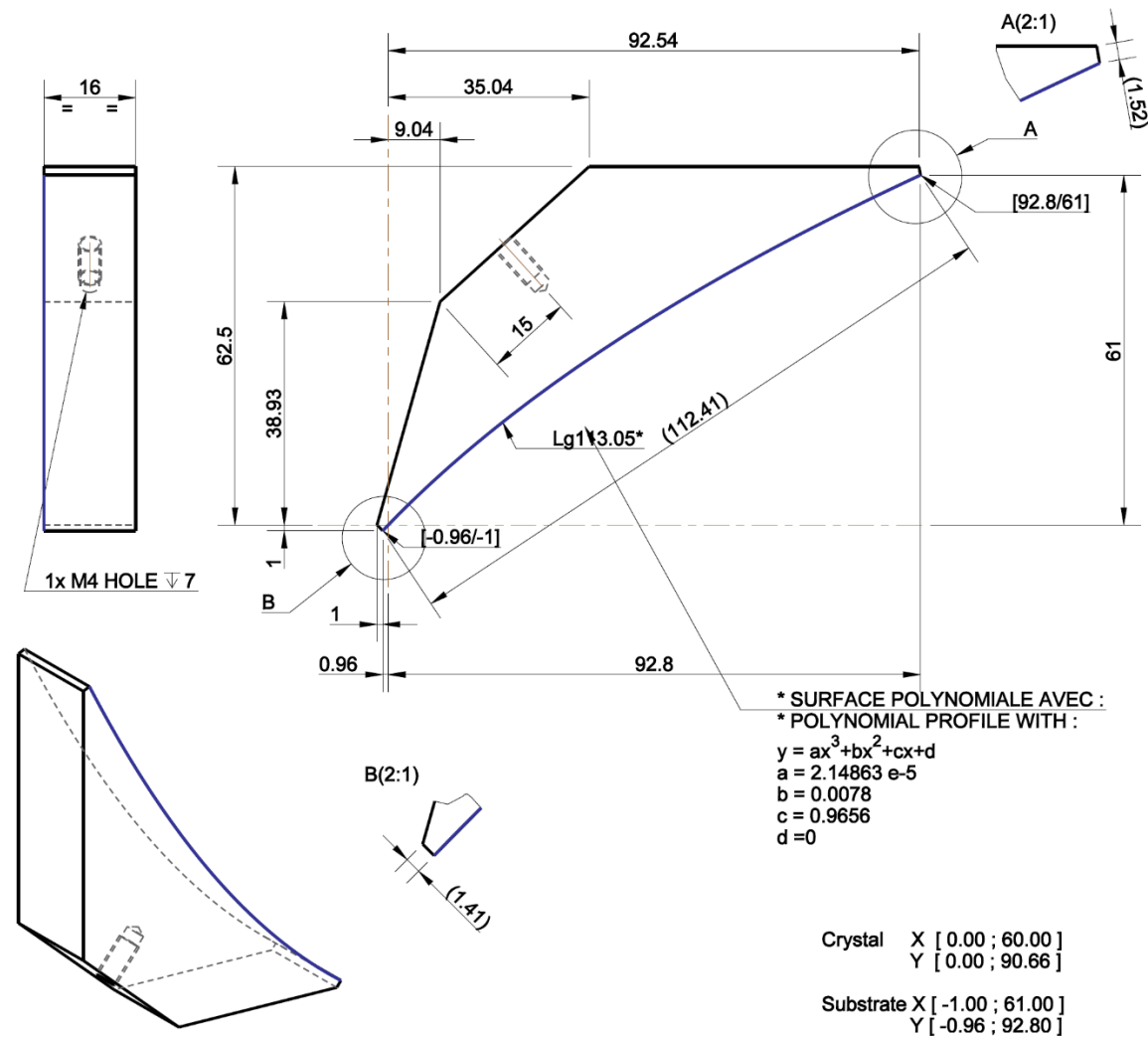


Figure 4: Schematic Drawing of Si(422) Crystal-3. The supplier shall generate required engineering drawings as per specifications given in Table 11

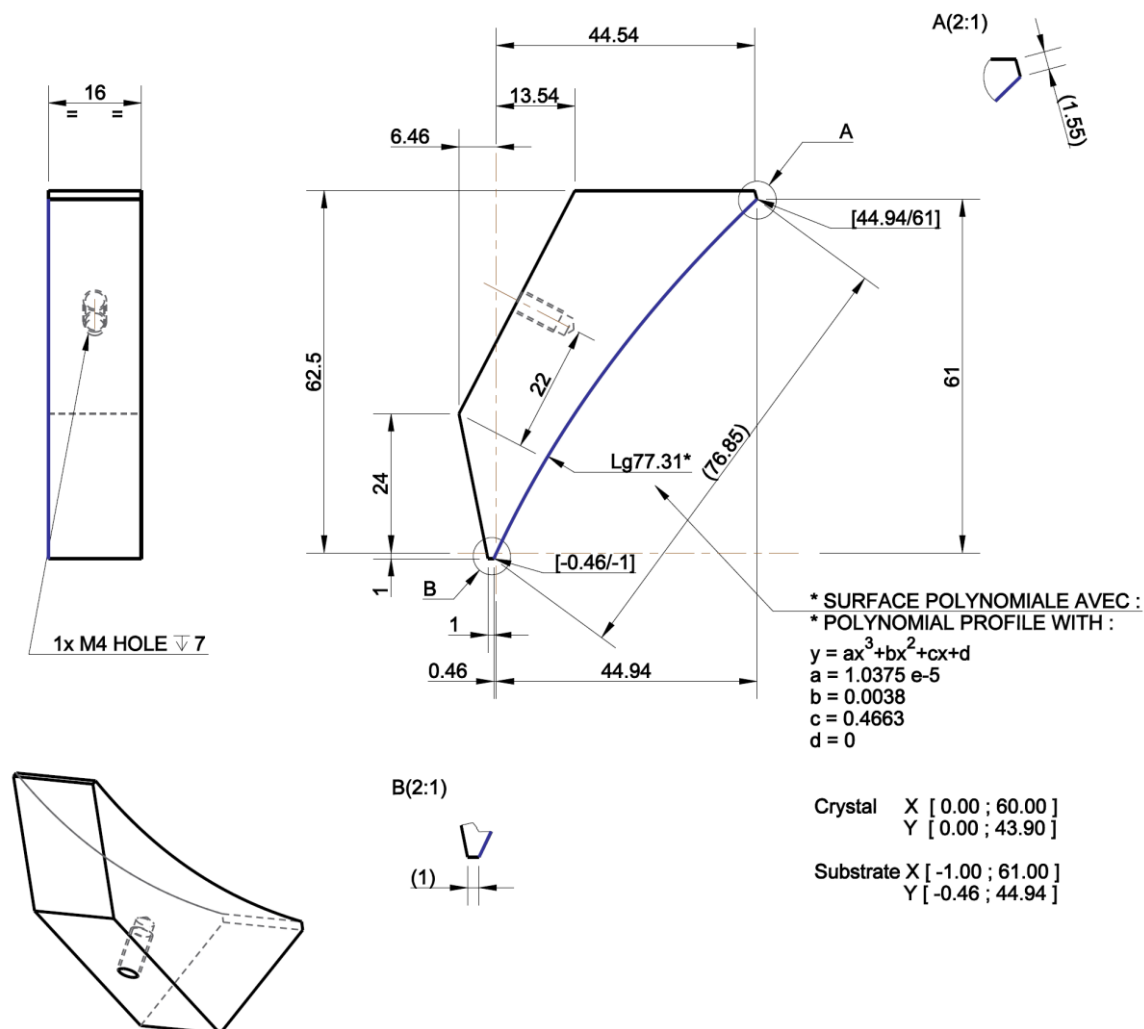


Figure 5: Schematic Drawing of Si(422) Crystal 4. The supplier shall generate required engineering drawings as per specifications given in Table 11

13 Appendix-II : Direction notation

Axis notation for 5 Axis stage assembly and the available space for it's integration along with the stage to controller (Vacuum-air interface)& controller to computer interface cabling Scheme

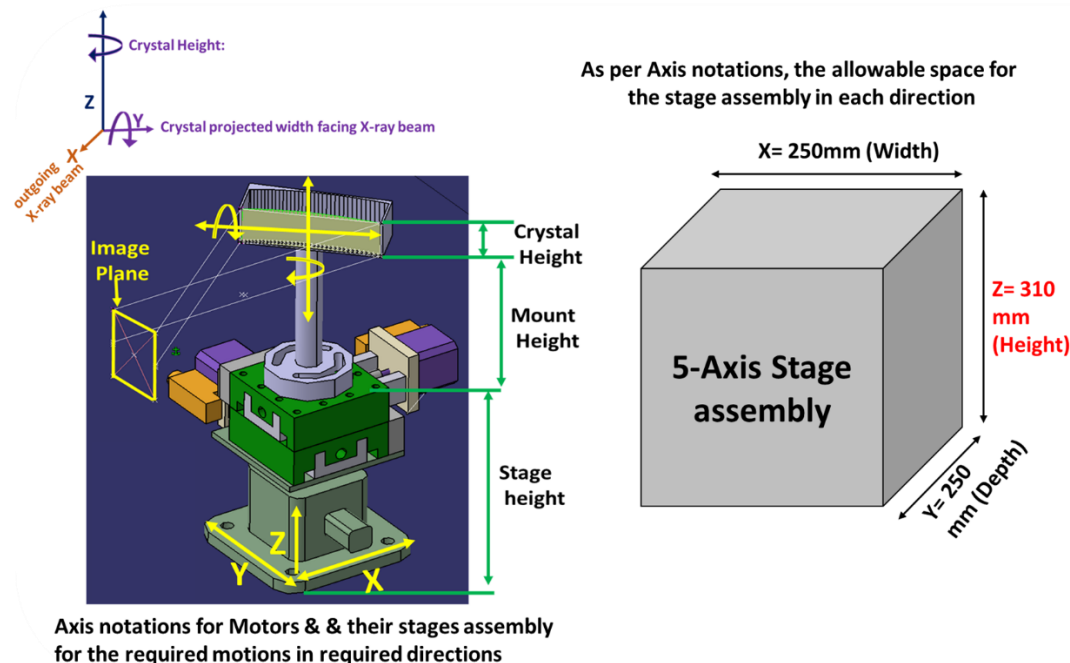


Figure 6: Axis notation for stage assembly in concept model & allowed space details for complete stage assembly. This is only representative CAD model.

14 Abbreviations

ITER	International Thermonuclear Experimental Reactor
IN-DA	Indian domestic agency
IPR	Institute for Plasma Research
XRCS	X-Ray Crystal Spectroscopy
PET	Pentaerythritol
GUI	Graphical User Interface
FAT	Factory acceptance tests
SAT	Site acceptance test
OEM	Original Equipment Manufacturer
COTS	Commercial Off-the-Shelf
CAD	Computer-Aided Design