# Statement of Work

(SOW)

Multi-purpose X-ray Diffraction (XRD) System

**H7TM01**

**1.0 Scope -** This Statement of Work (SOW) provides the requirements/specifications for the furnishing, shipping, assembling, installing, verification, calibration, testing, and training of a multipurpose x-ray diffraction (XRD) system suitable for diffraction applications including phase identification of both powders and crystalline corrosion deposits on aircraft parts, quantitative phase analysis of thermal spray powders including plasma spray powders and resultant thermal spray coatings, residual stress investigations, micro-diffraction, and single crystal orientation measurements in support of first article analyses, failure analyses, reverse engineering, and process engineering support. Furthermore, a modern multipurpose XRD system is required for crystalline phase identification of unknown powders in support of investigations by Bioenvironmental regarding worker health safety issues. The Analytical Chemistry Section, Oklahoma City Air Logistics Center (OC-ALC), Tinker Air Force Base, OK is responsible for the chemical analysis of metals and other materials used in the United States Air Force (USAF) aircraft and jet engines managed at OC-ALC. Current Classic metallurgical applications of XRD to aerospace includes ongoing Bragg Brentano (diverging line source) and parallel beam (collimated point source) geometries such as 1) determining the biaxial stress tensor including magnitude of principal maximum stress, magnitude of principal minimum stresses, and orientation angle as a function of depth into additively manufactured (AM) fatigue bar specimens 2) Single crystal orientation of engine components (Ni-based FCC) 3) Retained Austenite determination for aerospace bearing components using direct comparison method and 4) Analysis of Crystalline Polymorphs in Thermal Barrier Coatings using External Standard Method.

The contractor shall provide all labor, tools, equipment, materials, parts, personal protective equipment (PPE), transportation, shipping, and any other incidentals necessary to complete the requirements of this SOW. The contractor shall provide basic operational training for all supplied equipment/software to Tinker AFB personnel following installation by the contact acceptance by government personnel.

# Statement of Work

The contractor shall provide to the Government Point of Contact (GPOC) and the Contracting Officer, within 30 days of receipt of award, the following estimated milestone dates:

Estimated Delivery Date: Jun 1, 2027
Estimated Installation Date: Aug 1, 2027
Estimated Verification/Calibration Date: Sept 3, 2027
Estimated Training Date: Sept 10, 2027
Estimated Full Operational Capacity Date: Sept 15, 2027

## 2.0. SALIENT CHARACTERISTICS

**2.1.** **DESIGN –** The instrument shall be of the manufacturer's current design. It shall be a new unit and include any additional features necessary to comply with the requirements specified herein. Additional features which are not specified herein, but are part of the manufacturer's current design, shall be included in the furnished equipment.

**2.2.** **SAFETY –** The instrument shall be equipped with all necessary safety devices per National Electrical Code for protection against electrical shock hazard. It shall have all the necessary interlocks to prevent the accidental exposure of the operator to x-rays. It shall have any other protective devices as necessary to prevent injury to the operator, damage to the equipment, or erroneous data input or output.

**2.3.** **WARRANTY –** The complete spectrometer system, software, and interface boards will include an on-site 1-year warranty on all parts and labor to become effective on the day of installation acceptance by the government.

## 2.4. GENERAL SPECIFICATIONS

**2.4.1** XRD system shall have a highly accurate, highly precise two-circle goniometer capable of vertical theta-theta geometry. Goniometer platform is comprised of goniometer and interfacing for sample stage as well as incident and diffracted beam optics for Theta-Theta geometry with a radius of 240 mm. Goniometer platforms for both point focus applications and line focus applications include the goniometer, arms, Pre-Aligned Fast Interchangeable X-ray (PreFIX) module U-blocks for the incident and diffracted beam optics and preFIX module U-blocks for the sample stage accessories.

**2.4.2** XRD system shall have a maximum value for outer theta-1 shaft being no less than +178 deg and no greater than a minimum of -4 degrees, and the range for the inner theta-2 shaft being no greater than a minimum of -178 and no less than a maximum of +178 deg.

**2.4.3** XRD system shall have accuracy for each peak position equal to or better than ±0.01 degrees 2-theta over the whole angular range.

**2.4.4** The goniometer shall directly record angular positions by means of Heidenhain encoders that are mounted on the goniometer arms rather than the motors, allowing for real-time path tracking and repeatability of 0.0001 degrees and minimum positioning increment of 0.0001 degrees,

maximum slew speed of no less than 15 deg-per-sec and maximum axis scan speed range of no less than 2 deg-per-sec.

**2.4.5** Maximum continuous power of the high voltage power supply to the x-ray tube shall be at least 1.8 KW.

**2.4.6** The range of the high voltage of the x-ray tube shall be no less than 20-50 KV, adjustable in steps of 1 KV, and the range of the current to the x-ray tube shall be no less than the range of 5 to 60 amps.

**2.4.7** XRD system stability shall be better than (<0.005%) for both high voltage and current with 10% variation in the main supply.

**2.4.8** XRD system shall be capable of seamlessly switching between Parallel Beam (PB) or Bragg Brentano (BB) geometry via switching between spot and line focus without having to change optical components, and without manual realignment of optical components. It shall allow the physical rotation of the X-ray tube body that results in the anode surface being rotated from line projection to point projection as required for utilization of maximum X-ray tube flux in either line or point modes. Change of anode surface projection should be easy to accomplish even by inexperienced users in under 5 minutes without the need for realignment of the tube, optics or goniometer either manually or via computer and not require interruption of water flow to the tube itself during any part of the change.

**2.4.9** The XRD system shall arrive equipped with a cobalt LFF x-ray tube, Copper LFF x-ray tube, Cr LFF x-ray, and Mn LFF x-ray tube where each is capable of both line & spot focus. The diffracted beam secondary optics shall be appropriate for both parallel beam geometry and Bragg Brentano geometry. The diffracted beam secondary optics shall be capable of being upgraded to installing a monochromator to remove sample fluorescence when determining single crystal orientation of single crystal FCC nickel based super-alloys and when performing residual stress measurements.

**2.4.10** Incident beam optics, diffracted beam optics, and sample stages shall use PreFIX modules. The PreFIX modules shall be comprised of two main parts: a precision placing and locking device (T-block), and the module itself. The PreFIX modules are installed onto prefix position U-blocks on the incident and diffracted beam arms of the goniometer. The adjustable U-blocks are mounted in the PreFIX mounting positions on the goniometer.

**2.4.11** The only item that may need adjustment by the user is the tube height. When the tube height is correctly positioned with respect to the diffraction plane, no further system alignment shall be required. Tube height adjustment is needed only when the tube is changed or rotation of tube from line focus to point focus. The exchange/mounting of sample stages and interchanging incident beam and diffracted beam optical components using prefix modules will result in the system staying in optimal alignment and shall not require an adjustment of tube height or any other alignment-adjustment.

**2.4.12** XED system shall include Incident beam PreFIX module with holder for exchangeable fixed divergence slits. Divergence slits of 4, 2, 1, 1/2 and 1/4 degrees and beam width masks of 20, 15, 10 and 5 mm and mask holder (extra length 6 mm) are included, as well as soller slit holder and a holder for beta filters or attenuation foils.

**2.4.13** As an alternative to fixed divergence slits, XRD system shall additionally employ PreFIX mounted programmable divergence slit with automated slits with software controlled programmable divergence slit mechanism with automatic variable slit and fixed slit modes of operation. The variable mode allows for illuminated sample irradiation from 0.5 to 20 mm in 0.5 mm increments. The fixed slit mode allows for 1/32, 1/16, 1/8, 1/4, 1/2, 1, 2, and 4 degree slit sizes.

**2.4.14** For qualitative analysis of unknown powders, and quantitative analysis of plasma spray powders, XRD system shall be capable of rotation of specimen with computer-controlled motor to bring more crystallites into the diffraction position to reduce the influence of particle statistics on the measurements. This rotation would allow phi scans to improve particle statistics in both qualitative analysis of unknown powders and quantitative phase analysis of plasma spray powders and AM powders IAW with rigorous aerospace specifications. This PreFIX sample stage for sample spinning circular sample holders, with programmable phi-axis positioning or scanning. This stage shall be capable of being used in reflection or transmission mode.

**2.4.15** XRD system shall include a prefix mounted three-axis-Eulerian-cradle that possesses two rotation axes where one axis lies in the plane of the incident beam and diffracted beam and tangent to the sample surface (chi) and the other is normal to the specimen surface (phi). The three-axis-Eulerian cradle shall move in (height) z-translation. Chi must range from a minimum of -1 degrees to a maximum of no less than 91 degrees. Phi must range over 360 degrees. Z must range in height over no less than 64 mm. The maximum sample weight shall be no less than 2kg. The maximum sample diameter shall be no less than 140 mm. The maximum sample height shall be no less than 64 mm when using the three-axis-Eulerian-cradle.

**2.4.16** The XRD System shall be equipped with an incident beam prefix mounted X-ray lens (poly-capillary optics) for point focus applications, consisting of a few million glass capillaries (with an approximate diameter of 5 µm) formed together with a round cross-section and bent in a parabolic shape where the X-rays are transported through these very narrow glass capillaries using the effect of total external reflection inside the capillary. This lens shall include Beryllium windows for increased life. Dimensions of the X-ray beam through this polycapillary lens is diameter 8 mm with a divergence of 0.3 degrees. A crossed slit assembly is mounted on the front of the lens for direct control in both directions of the beam size from a minimum of no greater than 0.8mm up to a maximum of no less than 7mm. The slits can be manually adjusted (the scales are marked 0.02 mm divisions). The adjustment accuracy is +/- 0.02 mm. The x-ray lens shall be appropriate for Cu-Kα, Cr-Kα, Fe-Kα, Co-Kα, and Mn- Kα radiation.

**2.4.17** The XRD system shall be equipped with an incident beam PreFIX mounted housing with two crossed slits assemblies. The crossed slits assemblies consist of manually adjustable orthogonal slits with a maximum size of 10 mm to define both axial and equatorial divergence of the X-ray beam emitted by the focus of the X-ray tube. The housing shall incorporate a slot for

attenuation foil or beta-filter two crossed slits assemblies. The second crossed slits assembly (closer to the sample) acts as a divergence slit and an incident beam mask at the same time. The distance between the X-ray tube's focus and the position of the second crossed slits is used as defocusing correction in quantitative texture analysis. For microdiffraction applications the two crossed slits assemblies can be used to create a beam with a small spot size on the sample. The slits can be manually adjusted (the scales are marked 0.02 mm divisions) from 0 mm to 10 mm. The adjustment accuracy is +/- 0.02 mm.

**2.4.18** The XRD system shall be equipped with a Parallel Plate Collimator as a diffracted beam PreFIX module that consists of a set of parallel plates with equatorial acceptance angle of 0.27 DEGREES. A 0.1 mm slit for reflectivity measurements shall be included. The parallel plate collimator is capable of being combined with Soller slits and flat crystal diffracted beam monochromator.

**2.4.19** XRD System in point focus mode while using a prefix mounted poly-capillary optic in the incident beam, prefix mounted three-axis-Eulerian-cradle for the sample stage, and PreFIX mounted parallel plate collimator in diffracted beam shall be capable of Biaxial stress tensor determination as the result of an automated analysis capable of 30-two-theta scans at five different side-inclination-angles (chi-angles) equally spaced from zero-degrees to 70-degrees at each of six phi-angles (0 degrees, 30 degrees, 60 degrees, 90 degrees, 120 degrees, and 150 degrees). The stresses are then calculated at each of these six phi angles. The best fit biaxial stress tensor, principal stresses, and orientation angle are then calculated from these six stresses via least-squares algorithm for finding the 3 "best-fit" biaxial stress tensor elements: sig11, sig22, and sig12 according to equation: sig(phi) = sig11*[cos(phi)]^2 + sig22*[sin(phi)]^2 + sig12*sin(2*phi) where sig(phi) is the stress measured in a given direction (phi) of specimen for 6 different phi's. The maximum and minimum principal stresses and orientation angle (theta) are then calculated from these best fit biaxial stress tensor elements: sig11, sig22, and sig12 according to:

1) Maximum principal-stress = (sig11+sig22)/2 + {[(sig11-sig22)/2]^2 + sig12^2}^(1/2)
2) Minimum principal-stress = (sig11+sig22)/2 - {[(sig11-sig22)/2]^2 + sig12^2}^(1/2)
3) orientation angle (theta) is calculated from: tan (2*theta) = 2sig12/(sig11 - sig22).

**2.4.20** XRD system shall be capable of determining residual stress for the following alloys (column 1) using the following radiation (anode) (column 2) and corresponding wavelength of k-alpha-1 (column 3), Miller indices of reflecting planes (h,k,l) (column 4) and corresponding crystal structure (column 5) with corresponding 2-theta-peak-angle (column 5):

| | | | | | |
|---|---|---|---|---|---|
| Ferritic and martensitic steel | (211) | Chromium K-alpha | 2.28970 ANGSTROMS | BCC | 156-degrees-2theta-peak |
| Inconel 718 | (311) | Manganese K-alpha | 2.1018 | FCC | 163 |

| | | | | | |
|---|---|---|---|---|---|
| Ti-6-4 | (213) | Copper K-alpha | 1.5418 | HCP | 142 |
| Inconel 718 | (331) | Copper K-alpha | 1.5418 | FCC | 146 |
| 7075-Al | (331) | Chromium K-alpha | 2.2910 | FCC | 139 |
| 2024-Al | (511) | Copper K-alpha | 1.5418 | FCC | 163 |
| 2024-T3 | (311) | Chromium K-alpha | 2.28970 | FCC | 139 |
| Ti-6-4 | (211) | Cobalt K-alpha | 1.78897 | HCP | 145 |
| Austenitic Steel | 311 | Chromium K-alpha | 2.28970 | FCC | 148 |
| Austenitic steel | 400 | Cobalt K-alpha | 1.78897 | FCC | 156 |
| Aluminum | 420 | Cobalt K-alpha | 1.78897 | FCC | 163 |

**2.4.21** In addition to determining residual stress by side inclination angle technique (chi-angle), XRD system shall be capable of determining residual stress via omega-offsets by means of a parallel beam x-ray parabolic mirror in the incident beam and parallel plate collimator in diffracted beam.

2.4.22 Sensitivity, accuracy, and precision with respect to peak shifts as a function of side inclination angle in residual stress measurements allows discernment of peak shifts at no greater than 0.005-DEGREE-TWO-THETA-peak-shift.

2.4.23 XRD system shall be capable of crystal orientation analysis on FCC nickel based super-alloy single crystal HPT engine components via pole figure technique using parallel beam geometry. Pole figure analysis software shall show the location of a pole of the reflecting plane on a stereographic projection from the known angles of rotation of the crystal about various axes where reflection occurs while using the three-axis-Eulerian-cradle where corrections are made for absorption and defocusing as a function of chi. Pole figure analysis software shall show four Schmidt projections of the {2,2,0}-pole-figure. Pole figure analysis software shall show four Schmidt projections of the {1,1,1}-pole-figure. Pole figure analysis software shall show four Schmidt projections of the {3,1,1}-pole-figure. Pole figure analysis software shall show Schmidt projection of the {0,0,2}-pole-figure.

2.4.24 XRD system shall be capable of micro-diffraction with 100-micron-spot from a specific area on the sample using a mono-capillary optic and a video microscope to ensure proper alignment on the area of interest. XRD system shall be capable of XYZ translation of sample to allow for accurate alignment and maping of sample in x-ray beam in a micro-diffraction application via a five-axis-Eulerian-cradle with phi and chi rotation axes as well as x, y, and z translations. 2D

diffraction patterns of very small (spots on) samples shall be obtained by a XRD system detector (CMOS-pixel-area-detector) operating in 2D mode.

2.4.25 XRD system shall be capable of determining Residual austenite using the direct comparison method for austenite contents below 15% where quantitative microscope methods become unreliable, and where substantial amounts of carbides may be present and where the sample may be strongly textured.

2.4.26 XRD system shall be capable of quantification of the monoclinic, tetragonal, and cubic polymorphs of the Y2O3-stabilized ZrO2 (YSZ) by the external standard method.

2.4.27 XRD system shall be capable of phase quantifications by internal standard method, method of standard additions, reference intensity ratio (RIR) method, constrained XRD phase analysis using generalized internal standard method using XRF-determined elemental concentrations, and whole pattern fitting with Rietveld refinement.

2.4.28 XRD system detector shall be a CMOS pixel read-out chip of high spatial resolution, high dynamic range, and low noise working in single photon counting mode.

2.4.29 XRD system detector shall be capable of operating as a point detector where all pixels are added up to give one intensity value as a function of time (0D mode), line detector (1D mode) where all pixels in one column are added up to for a position sensitive detector in one direction, area detector (2D mode) where all pixels are read out independently with direct observation of the x-ray image, and 3D mode where all pixels are read out independently while many 2D images are combined to reconstruct the voxels of the object: computed tomography where three-dimensional images of the specimen are generated from a larger series of two-dimensional x-ray images taken around the specimen.

2.4.30 The XRD system detector (CMOS-pixel-area-detector) shall as a minimum have a 256-by-256-pixel-array with no greater than 55-micron-pixel-size and no less than 97 percent count rate linearity up to no less than 50,000 cps per pixel and no less than 12,800,000 cps per strip. When operating in 0D mode as a point detector, it shall have a high dynamic range of no less than 99% linearity range from 0 to no less than 6.5 x 10^9 cps.

2.4.31 The static 2-theta range of the CMOS-pixel-area-detector shall be at least 3.3 degrees at standard 240 mm radius.

2.4.32 CMOS-pixel-area-detector shall be compatible with Cr, Cu, Co, Fe, and Mn radiation.

2.4.33 The x-ray tube must be manufactured by the supplier of the XRD system (for total system responsibility) and have self-contained water lines for superior temperature control and stability.

2.4.34 The XRD system must be supplied with an X-ray tube of the long fine focus design (0.4 x 12 mm) with a maximum loading of 1.8 kW. The tube shall have ceramic insulation that provides superior focal stability over glass tubes.

2.4.35 Tube design must allow the physical rotation of the X-ray tube body that results in the anode surface being rotated from line projection to point projection as required for utilization of maximum X-ray tube flux in either line or point modes. Change of anode surface projection should be easy to accomplish even by inexperienced users in under 5 minutes without the

need for realignment of the tube, optics or goniometer either manually or via computer and not require interruption of water flow to the tube itself during any part of the change.

2.4.36 Separate from the generator, the X-ray tube must include an electronic chip that specifies the maximum generator settings for the specific source material, identifies the tube anode and serial number automatically to the system software, and records use parameters such as hours of use for a tube.

2.4.37 A dial gauge shall be integrated into the XRD system so that the specimen surface lies on the diffractometer axis and shall remain there as the side inclination angle (chi) is changed during measurements of residual stress.

2.4.38 Single crystal orientation of turbine blades shall be by pole figure analysis determinable by both the Schulz reflection method using Bragg-Brentano geometry and the Field and Merchant method employing parallel beam geometry.

2.4.39 The XRD system shall operate using single phase, 230 volt, and 60 Hz electrical power.

2.4.40 XRD system shall be equipped with Soller slits of 0.04 radians, 0.01 radians, 0.02 radians, and 0.08 radians for incident and diffracted beam.

2.4.41 XRD system shall be equipped with Prefix mounted Sample stage for flat samples.

2.4.42 External chiller unit with air-cooled condenser to cool the x-ray tube.

**2.5 ANALYTICAL SOFTWARE**

2.5.1 Data acquisition software contains the following functionality: data acquisition based on the XRDML platform, measurement strategy determination tools, configuration and measurement management, automatic processing, data conversion and viewing functionality for XRD systems.

2.5.2 Software shall support the multi-hkl method of stress analysis.

2.5.3 Software shall perform data treatment and XRD phase identification while using the ICDD PDF database and Crystallography Open Database (COD). The search-match algorithm shall use peak and profile data. There shall be graphics for examining, displaying, and editing diffractograms. Reference Intensity Ratio (RIR) shall be used for estimation of phase quantities. Software shall have Rietveld refinement capability, ability to calculate diffraction pattern from a crystal structure, ability to model a simulation to resemble real data, and ability to manually refine model to resemble real experimental data.

2.5.4 Software shall contain a program for the measurement of residual stress. It shall combine classical uniaxial and biaxial sin^2 (psi) residual stress analysis with an x-ray elastic constants database, with all established methods for peak position determination and routine for correcting minor misalignments of the sample and diffractometer systematic errors. It shall contain a database with elastic constants for no less than 400 materials, as well as correction algorithms for residual misalignments. Software shall allow free choice of user configurable defaults and instant recalculation of all results upon any change of input parameters.

2.5.5 Software shall contain a program for quantitative texture analysis with comprehensive graphics tools. It shall include corrections on experimental pole figures and calculation of orientation distribution functions (ODF), pole figures and inverse pole figures according to the WIMV method. It shall read texture data files based on the XRDML platform.

2.5.6 The software allows 2D microdiffraction data to be used for further analysis. Software allows the raw and integrated CMOS pixel area detector data to be viewed. The data integration results into Debye-Scherrer strip data, computed tomography input data, and diffractograms for subsequent analysis. Software converts 2D data into 1D data based on predefined areas. The software can perform mathematical operations on 2D data and provides basic analysis tools.

2.6 COMPUTER SYSTEM

2.6.1 The computer system shall be at least a 7th Gen Intel® Core™ i7 6700 Quad-Core Processor (3.20GHz, 4.0Ghz Turbo, 8MB w/ HD Graphics 530) Windows® 10 64- bit Operating System, 500 GB Hard Drive with 34" widescreen monitor.

2.6.2 The software licensed to be used on the computer shall include Windows 10 operating system with MS word, MS Excel, and MS PowerPoint.

**2.7 ACCESSORIES**

2.7.1 The supplier will supply any unique supplies required for the operation of the instrument and supply of consumables to allow the operation of the instrument for 60 days. This is to allow the end-user sufficient time to establish a source and acquire suppliers.

2.7.2 All special tools to facilitate the efficient operation required for routine maintenance and efficient operation shall be supplied with the instrument.

2.7.3 A knife edge for tube height alignment shall be provided.

2.7.4 Copper attenuation foils of thicknesses 0.1 mm and 0.2 mm for alignment procedures that require protection of detector shall be included.

2.7.5 A pressed silicon powder sample with diameter no less than 30 mm and thickness no less than 2 mm shall be supplied with the system to perform standard verification tests.

2.7.6 A rolled copper specimen for texture verification tests with indicated rolling direction shall be provided that is no less than 20 mm x 20 and thickness no less than 1 mm.

2.7.7 A thin film sample shall be provided for reflectometry verification. The Thin film sample shall be a glass plate onto which a chromium film between 20 nm thick has been applied.

3 ON-SITE INSTRUMENT INSTALLATION, VERIFICATION, AND TRAINING

**3.1** The VENDOR is available to perform a pre-installation inspection to advise of any pre-installation work that may be required. This pre-installation survey is provided at no charge.

**3.2** The vendor shall provide on-site verification by demonstration that the instrument is in working order and meets the salient characteristics of this item description.

**3.3** The vendor shall provide a minimum of one day on-site initial training in the use of the instrument during the installation. This training will cover all aspects of safely operating the diffractometer.

**3.4** The installation of the x-ray system will be performed by a factory trained service engineer after notification by the purchaser that the shipment has arrived and that all pre-installation work is completed.

**3.5** When the installation is completed, the installation engineer performs the Factory Acceptance Test (FAT). The FAT is a series of electrical and mechanical tests that duplicate the quality and performance tests done in the factory prior to shipment. When the system passes the FAT, the customer then signs the FAT results form acknowledging that the system successfully duplicated or exceeded all functional requirements. At this point the system warranty begins.

**3.6** After the FAT is completed, a System Acceptance Test (SAT) is performed. The SAT consists of demonstrating to the customer how to set up and use the system and is performed by the installation engineer. This demonstration shall verify that the system is ready for use by the customer.

**3.7** Application training is provided to the customer at no further cost where application training will be performed for a minimum of three days on site within three months of the completion of the SAT in the use of the instrument as it pertains to all items of this SOW.

**4.0. QUALITY ASSURANCE**

**4.1** QUALITY CONFORMANCE INSPECTION

**4.1.1** The instrument shall meet the salient characteristics of this item description, conform to the vendor's own drawings, specifications, standards, and quality assurance practices.

**4.1.2** After installation, instrument verification, and training are completed at Tinker Air Force Base, a Government representative shall perform quality conformance inspections on a fully assembled and fully operational spectrometer. Until accepted by the Government, the vendor shall be responsible for deficiencies and installation

costs.

**4.1.3** Demonstrate in the presence of a government representative that the system meets or exceeds those specifications set forth in Section 2.

**4.1.4** The Factory Acceptance Test (FAT) referenced in section 3 will include a goniometer linearity test and reproducibility test carried out using a Si powder sample showing the factory and field values for the peak positions of eight diffraction peaks using Bragg-Brentano geometry. The bandwidth must be less than 0.02-degrees-2theta. The reproducibility must be less than 0.002-degrees-2theta.

**4.1.5** The FAT will include two measurements of residual stress in a stress-free Tungsten sample consisting of tungsten powder sprinkled onto a glass plate using the side inclination angle technique (chi-angle). This measurement will be at 2theta = 126.707 degrees using the 321-reflection where measaurement-1 is for the double-crossed-slits-collimator in the incident beam and measurement-2 is for the polycapillary lens in the incident beam while the parallel plate collimator in the diffracted beam for both measurements. Determinations of the peak-2theta for both measurements will be at chi = -45 degrees, chi = + 45 degrees, and chi = 0 degrees. The difference in the peak-2-theta at chi = -45 degrees and peak-2-theta at chi = + 45 degrees shall be less than 0.02 degrees 2-theta for both measurements. The reproducibility shall be less than 0.005 degrees 2-theta.

**4.1.6** The FAT will include a thin film functional test involving a thin film (Cr) sample that is 20 nm thick with a 1/32-degree-divergence slit in the incident beam and parallel plate collimator with 0.1 mm slit in the diffracted beam. The 2theta-omega-scan shall show X-ray-intensity as a function of 2theta-angle from 0 degrees-2theta to 2.0 degrees-2theta with five maxima present in the fringe pattern.

**4.1.7** The FAT will include a texture analysis using the rolled copper specimen of section 2.7.