Nevis NuSTAR X-ray Calibration Facility

Prepared by: Nicolai Brejnholt and Chuck Hailey

Introduction

This memo describes the NuSTAR X-ray calibration facility with particular emphasis on radiation shielding and operational safety features. The memo provides an overview of the NuSTAR project, the X-ray calibration facility at Nevis Laboratory, the radiation levels and shielding, and source operational details (e.g. operational procedures, radiation interlock system and other safety features).

Overview of NuSTAR project

NuSTAR is a NASA satellite mission (total mission cost $105 Million) designed to carry two X-ray telescopes into a low earth orbit. Caltech is the overall lead institution. Hardware is provided by Caltech (X-ray detector lead institution), Columbia University (optics lead institution including optics fabrication and calibration), UC Berkeley (anticoincidence shield), Danish Technical University (optics coatings) and NASA Goddard Space Flight Center (glass production). Management is provided by the NASA Jet Propulsion Laboratory. The launch will take place in fall of 2011. NuSTAR will be the first space-based observatory to carry telescopes capable of focusing X-rays above 10 keV with high efficiency (~1000 times more sensitive than previous missions) and angular resolution (~ 1 arcminute).

In addition to building the X-ray optics at Nevis Laboratories, Columbia is also the lead institution for the optics calibration. After an extensive review it was decided that from a cost, risk and availability standpoint the best approach was to calibrate the optics in-situ at Columbia. Calibration requires an X-ray source operating from 6-80 keV (the operating range of NuSTAR) and a beamline ~140 meters to adequately simulate stellar sources (the great length is driven by the ~10 meter focal length of NuSTAR). This led to a plan to place an X-ray source in the neutron tunnel adjacent to the Cyclotron building at Nevis. The beam could be directed into a clean room housing the NuSTAR optics on the Cyclotron building floor only meters away from where the optics were being constructed.

NuSTAR calibration facility

Referring to Figure 1 and Appendix Figure A1 the calibration facility is seen to comprise six parts. A high power X-ray source sits at the far end of the (underground) neutron tunnel. The X-ray beam enters the Cyclotron building through a concrete wall. The X-ray optics are housed in a clean room on the Cyclotron building floor and 10 meters away through another pipeline a second room houses the X-ray detectors. The facility is operated from a single control room.

Following the source room the beam line consists of a 160m long PVC pipe with incrementally increasing diameter (from 4” at the source end to 20” near the tunnel exit) followed by the calibration bench and another 10m of 20” PVC piping leading up to the X-ray detector. The PVC pipe will contain as low as 0.1Torr vacuum and have windows consisting of Kevlar backed Mylar at the largest diameters (20”) and Mylar at the smaller diameter opening. Most of the 160m of vacuum pipe leading up to the calibration bench is located inside the neutron tunnel along with the X-ray source. The tunnel entrance is sealed by a 60cm thick concrete slab and more than a centimeter of steel plating.

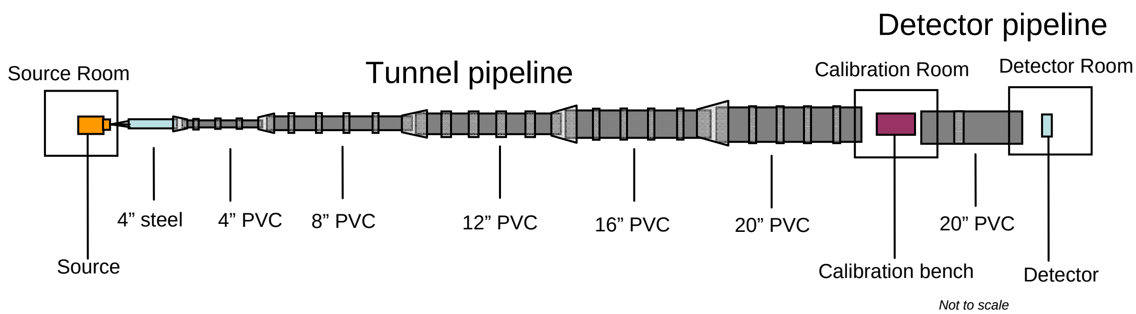


Figure 1

At the exit of the 160m vacuum pipe the calibration bench will sit in a small clean room. The last 10m section of vacuum pipe will exit this room and lead to the detector room which will be temperature controlled only.

Radiation Shielding and Dose Calculations

Radiation Shielding Design Approach:

The approach we followed in calculation of radiation doses and design of shielding is ultraconservative. It presupposes ***an operational procedure in which there is no physical access to the X-ray source at the end of the beam tunnel (or even access to the tunnel) or the direct X-ray beam from either the optics or detector clean rooms during X-ray source operation***. Thus the purpose of the radiation shielding is to prevent exposure to ambient radiation leakage from the pipeline, calibration room and detector room on the main Cyclotron building floor. Radiation shielding calculations were not designed to accommodate appropriate Federal Regulations for radiation workers for anticipated operating times. Rather, the ***radiation shielding was designed under the appropriate Federal Regulations of exposure for individual members of the general public, and for dosages corresponding to an exposure of 365 days a year, 24 hours per day.*** This approach was mandated because the Cyclotron building floor is generally accessible to a wide range of researchers not associated with the NuSTAR team, and who work on the floor for long periods of time. Inasmuch as these researchers are not radiation workers on the NuSTAR team, the radiation shielding design was meant to accommodate them. Finally, the ***calculations were augmented by safety margins at high energies varying from a factor of 10-100.***

Dose limits

Federal Regulation 56 FR 23398 Part 20.1301 states that individual members of the public must not be exposed to a total effective dose equivalent of more than 1mSv per year. Part 20.1004 states that for X-ray radiation 1Sv=1Gy=1 J/kg. Assuming a worst case scenario of personnel working around the clock for 365 days a year, the individual weighing 50 kg (low mass provides worst case) and expressing energy in electron volt we find the maximum allowed dose equivalent

$$d_{max} = \underline{9.9 \text{ x } 10^9 \text{ eV/s}}$$

X-ray production

The X-ray system is a commercial turn-key unit – the COMET Module XRS-100 utilizing a COMET MXR-102 X-ray tube (see appendix for tube documentation). This setup meets norm 21CFR §1020.40 for cabinet X-ray systems. The system will be located in the source room shown in Appendix Figure A1, A2 and A5. The output X-ray spectrum from the tube used for the shielding calculations is indicated in Figure 3. The spectrum was generated using available simulation tools for electron impact sources, and as a worst case, using the maximum power generation of the X-ray tube.

Shielding requirements

Photoelectric and scattering cross-sections used for the simulations were those given in the National Institute of Standards and Technology data base. The code used for simulations (see below) also takes into account X-ray fluorescence effects, which are significant for high atomic number materials at high energies. This is important since a substantial number of X-ray fluorescence photons can be produced when high energy (> 70 keV) X-rays impinge on shielding materials. These fluorescent K-X-rays are highly penetrating in shield materials, since their energies are below the characteristic K-edge that produced them. Stopping these fluorescence X-rays can require substantially thicker shielding than would otherwise be required.

Geant4 simulation

The baseline geometry has been constructed in Geant4 and is illustrated in Figure 2. The pipeline is indicated in yellow, the optics is green and other objects (walls, floor and optics fixture and mandrel) are shown in blue. The vacuum sealing windows are designated by brown surfaces. The detection volume used is indicated in red and extends around the entire volume situated outside the tunnel. Each square covers an area of $1 m^2$ and is set to detect photons up to 100 keV.

The expected spectrum and intensity of the Comet source at maximum power is shown as the blue line in Figure 3. The green line is the spectrum simulated in Geant4. The number of photons in the Geant4 simulation was limited by computation power so a scaling factor must be applied to the results. We assume here that the radiation spectrum and intensity will be given by the red line in Figure 3 as a worst case and calculate the scaling factor *s* for the total number of photons to be $s = 126$. The X-ray source spectrum for the simulation overestimates the actual spectrum by a factor of ~10-100 above ~60 keV, to provide some conservatism for the most penetrating X-rays in the calculation.

Note that the peaks near 60keV and 70keV in the Comet spectrum derives from the Tungsten (W) target material in the X-ray tube.

To estimate the shielding requirements we first consider the count rates in the facility for the case of zero shielding. There are two components to the relevant X-ray beam. The first one is the direct beam that goes down the beam line and out the end of the pipe. The second component is the scattered X-radiation along the length of the beam line. For the unshielded case, the direct X-ray beam will be brightest compared to the scattered X-radiation.

In the following we take the sum of the counts in the four squares overlapping the center of the beam line to describe the direct beam. The spectrum obtained is plotted in Figure 4 along with the spectrum of the square with the most scattered photons.

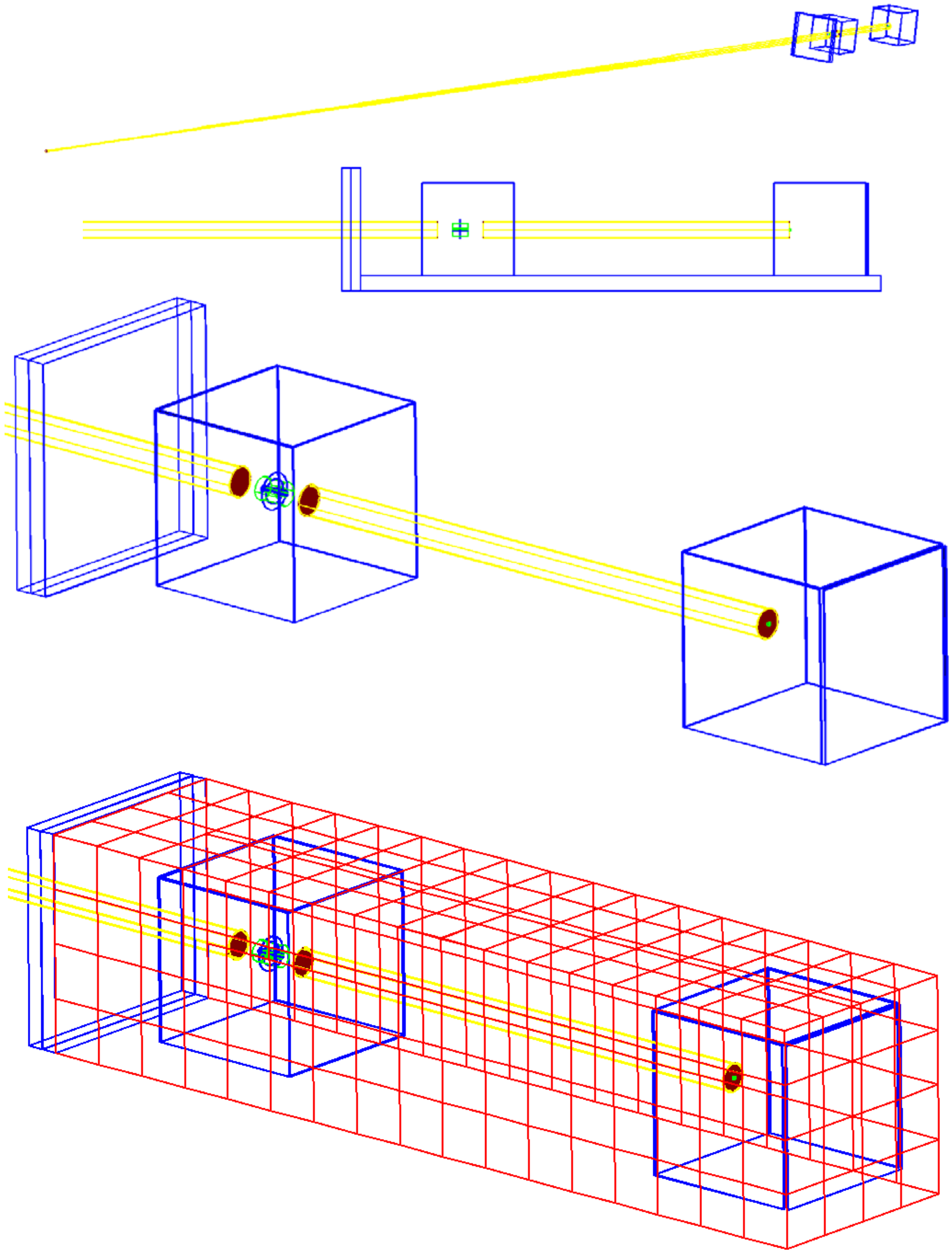


Figure 2

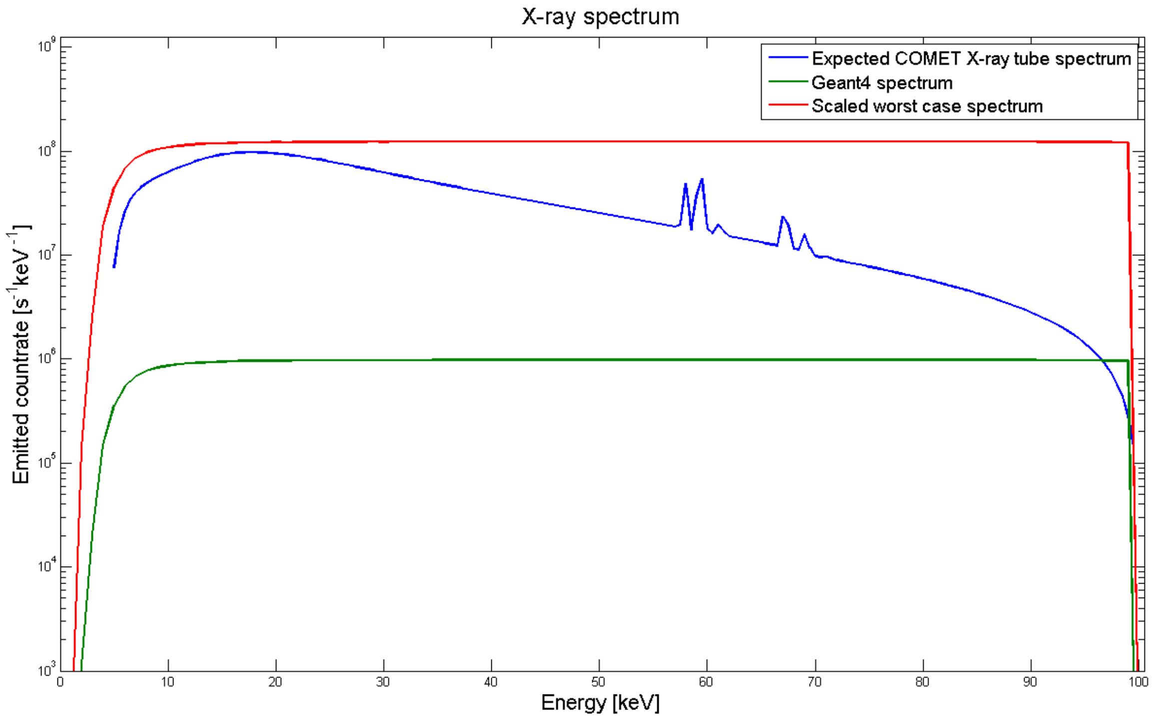


Figure 3

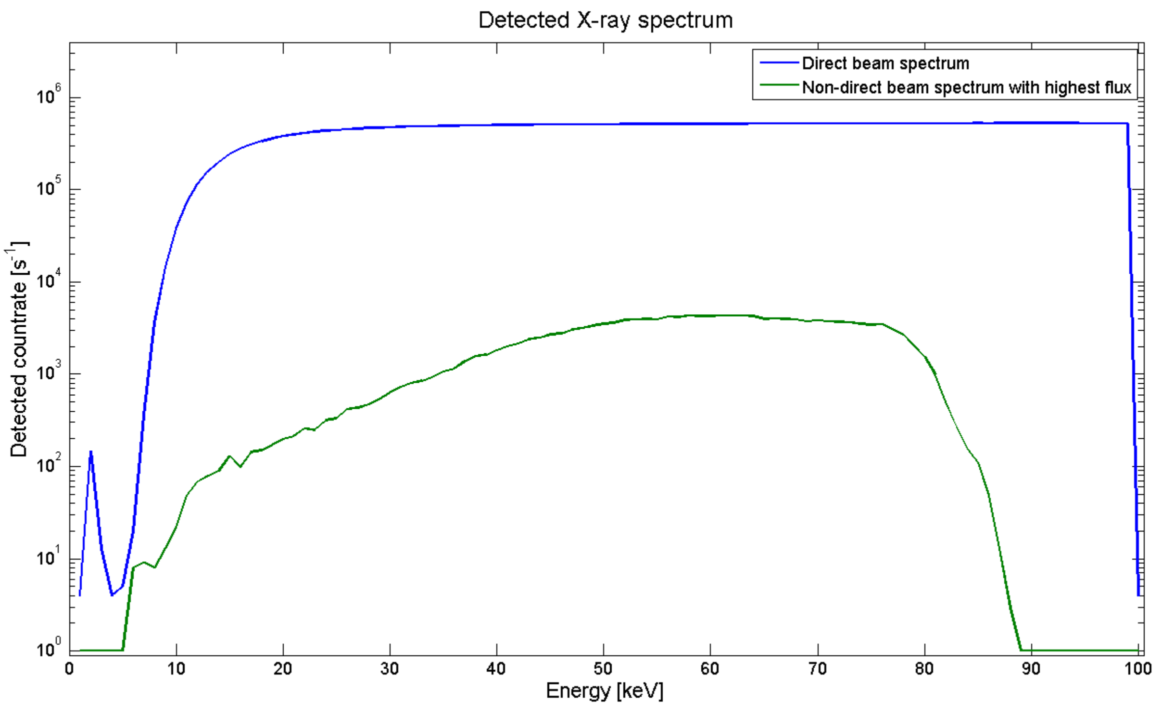


Figure 4

Summing over all bins we find that less than 46 million photons are detected in the direct beam and less than 160000 in the highest flux scattering square. We round these numbers to 50 million and 200000, respectively, and apply the scaling factor. ***Assuming a worst case scenario of all photons hitting the detection area having energy 100 keV*** we find that the direct beam and scattering square receives

$$d_{direct} = \underline{6.3 \text{ x } 10^{14} \text{ eV/s}}$$

and

$$d_{scatt} = \underline{2.5 \text{ x } 10^{12} \text{ eV/s}}$$

respectively. From this, and the maximum allowed dose equivalent d_{max}, ***we find that a total of five orders of magnitude attenuation is required for the direct beam case and three for the scattering squares.*** This level of attenuation could be achieved by roughly 2mm of lead for the direct beam and about 1mm for the scattering squares. However, to reduce X-ray fluorescence effects an initial layer of 1mm lead sheets followed by ~2.5cm of heavy concrete (primary mass constituent being Barium-56) will be used on the walls of the calibration room and the detector room. The direct beam stop will also consist of a layer of heavy concrete, but will be backed by lead bricks ($5\text{x}10\text{x}20\text{cm}^3$), not lead sheets. Exposed sections of the pipeline will be wrapped in 3mm of lead sheet.

Implementing the above shielding in the Geant4 simulation the resultant output spectra from the direct beam area and the highest scattering flux square are shown in Figure 5. This result was obtained by summing up all the energy bins. For those bins in which no counts were recorded we rounded up to one count. This accounts for statistical fluctuations in the simulation. One can readily show that estimating the true mean counts per bin (where zero counts were recorded in the simulation) by one count has less than one chance in a thousand of underestimating the total mean counts for all the bins so rounded up. Even in that case, the underestimate of total counts is much less than a factor of two. Thus summing up all energy bins, rounding those with zero photons to one, we have less than 100 (0 before rounding, 100 after) photons in the direct beam and less than 150(35 before rounding, 104 after) in the scattering square. Applying the scaling factor and assuming all detected photons have energy 100keV this amounts to

$$d_{d,shield} = \underline{1.3 \text{ x } 10^{9} \text{ eV/s}}$$

and

$$d_{s,shield} = \underline{1.9 \text{ x } 10^{9} \text{ eV/s}}$$

respectively.

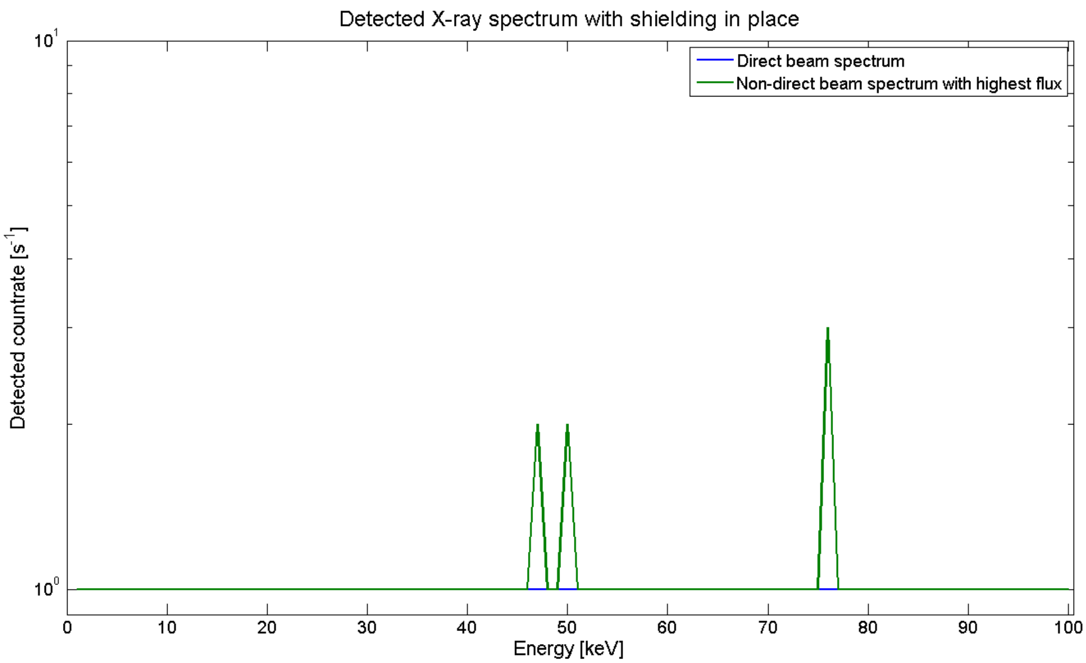


Figure 5

To sum up the worst case scenario constructed above, we note that we have assumed all photons being detected to have energy 100keV and the number of photons to be well above what is expected from the Comet X-ray tube. On top of this the simulation results have been rounded up for additional conservatism. Furthermore the maximum allowed dose equivalent assumes a member of the public will be present at the X-ray facility every single second of an entire year. Even in this worst case scenario the planned shielding will bring the radiation levels well below d_{max}, ***the federally-allowable dose for a member of the general public; the calculated levels are 5-8 times less than the allowable dose for the direct and scattered beam respectively, with a safety margin of 10-100 times.***

Operating Procedures and Safety Protocols

The overall safety philosophy and operational procedures are based on the following principles:

1) There is no direct access to the X-ray beam at any point in the beam line (at the X-ray source, in the beam tunnel, in the optics room or in the detector room) while the X-ray generator is in operation.
2) The X-ray source is run remotely and thus there is never a need for personnel to be in proximity to the X-ray source during operation
3) The entire facility (X-ray source room, optics room and detector room) is interlocked such that any unauthorized attempt to enter any of these rooms during X-ray “on” condition will immediately shut down the X-ray source.
4) Access to the above rooms cannot take place while the X-ray source is in operation. The room access is controlled by keys to unlock doors. The keys are obtained in the X-ray source control room, and removing the keys from their control room position physically breaks the electronics circuit running the X-ray source. Thus if any of the keys to the rooms is out of the control room, the X-ray source cannot be run.

5) Access to any of the above rooms is monitored by cameras, a PA system is used to announce “beam on” and, in addition, warning lights are wired into the X-ray source circuitry so that they are in “on” position whenever the source is on.
6) Each room contains clearly identified panic buttons whose activation immediately shuts down the beam.
7) All personnel who operate the X-ray source will undergo training from Comet X-ray source personnel as part of the X-ray source checkout. Other personnel will be certified in the same manner by qualified Columbia personnel.
8) A radiation survey will be conducted during initial checkout of the X-ray source.

Further Details

Appendix Figure A2-A9 shows the details of the radiation interlock and warning system. A key panel will be situated in the control room. Turning on the X-ray generator will only be possible when *all* keys allowing access to the shielded areas are in the key panel. Four of these keys will exist, one for tunnel access through the source room, one for tunnel access through the middle room, one for calibration room access and one for detector room access.
All doors to the shielded areas will be mechanically interlocked with multiple electrical contacts on each door wired in series. Any contact not closed disallows turning the X-ray generator on.
In addition to the interlock keys, the X-ray source will have a key of its own, which can only be turned to “power on” after a designated pre-warning period has passed. During this pre-warning time a special optical and acoustical alarm will sound, allowing personnel to hit one of multiple large, obvious kill-switches located inside and outside the shielded areas, prior to the X-ray source being turned on, if they perceive personnel to be at risk of exposure. The kill-switches will cut the power to the X-ray generator and require a special key, located in the control room key panel, to reset. The kill switches will be distributed throughout the facility as indicated by Appendix Figures A2 and A4-A9. After the X-ray source has been successfully turned on, red lights will indicate radiation is “on” near and inside the shielded areas. In addition to these safety protocols, and the shielding previously discussed, all personnel at the facility will be required to wear film badges which are sent in for screening on a monthly basis.

Experience of Senior Personnel Involved in NuSTAR Calibration Facility

Professor Chuck Hailey (Columbia)

Prof. Hailey has more than 25 years experience operating high power X-ray sources and running X-ray facilities. He constructed the $1.5 Million X-ray calibration facility used for the European Space Agency Newton Observatory Reflection Grating Array while at Lawrence Livermore National Laboratory, and rebuilt the same facility when he came to Columbia University in 1995. He also ran the Livermore X-ray Calibration Facility from 1988-1992. The XCF was the largest X-ray calibration facility in the world, and included the High Energy X-ray Source (HEXS), the highest brightness hard X-ray source in regular operation at the time. The operating characteristics of the HEXS are almost identical to those of the planned NuSTAR facility. Prof. Hailey has extensive experience in the design, construction and operation of X-ray sources, and has worked with a wide variety of high power commercial units.

Dr. Finn Christensen (Danish Technical University)

Dr. Christensen has operated the X-ray calibration facility of the Danish National Space Agency for more than a decade. He designed the facility, and it has been used to calibrate numerous X-ray instruments for space experiments including the telescopes for the Spectrum X-Gamma Mission and the optics for the High Energy Focusing Telescope (HEFT) mission.

Mr. Norm Madden (Columbia)

Norm Madden is an electrical engineer. During his 30+ year career with the University of California Lawrence Berkeley and Lawrence Livermore National Laboratories he gained extensive experience in the development of interlock and warning systems for intense particle beam, radiation and explosive facilities. Mr. Madden is an expert on high voltage systems of the type employed in the Comet X-ray source.

Mr. Todd Decker (University of California Berkeley and Lawrence Livermore National Laboratory)

Todd Decker is the project engineer for the NuSTAR calibration facility. He has over 30 years of experience as a mechanical design and project engineer and is a licensed general contractor in California. He is responsible for the overall design of the calibration facility and its construction, working in coordination with Columbia facilities. Mr. Decker designed the entire Nevis Cyclotron Laboratory facility in 1995 and was the general contractor for its construction. He has extensive experience on space-based experiments, serving as Project Engineer for the Newton Observatory Reflection Grating Array and Project Mechanical Engineer for HEFT. He is also the lead mechanical engineer for the optics on NuSTAR.

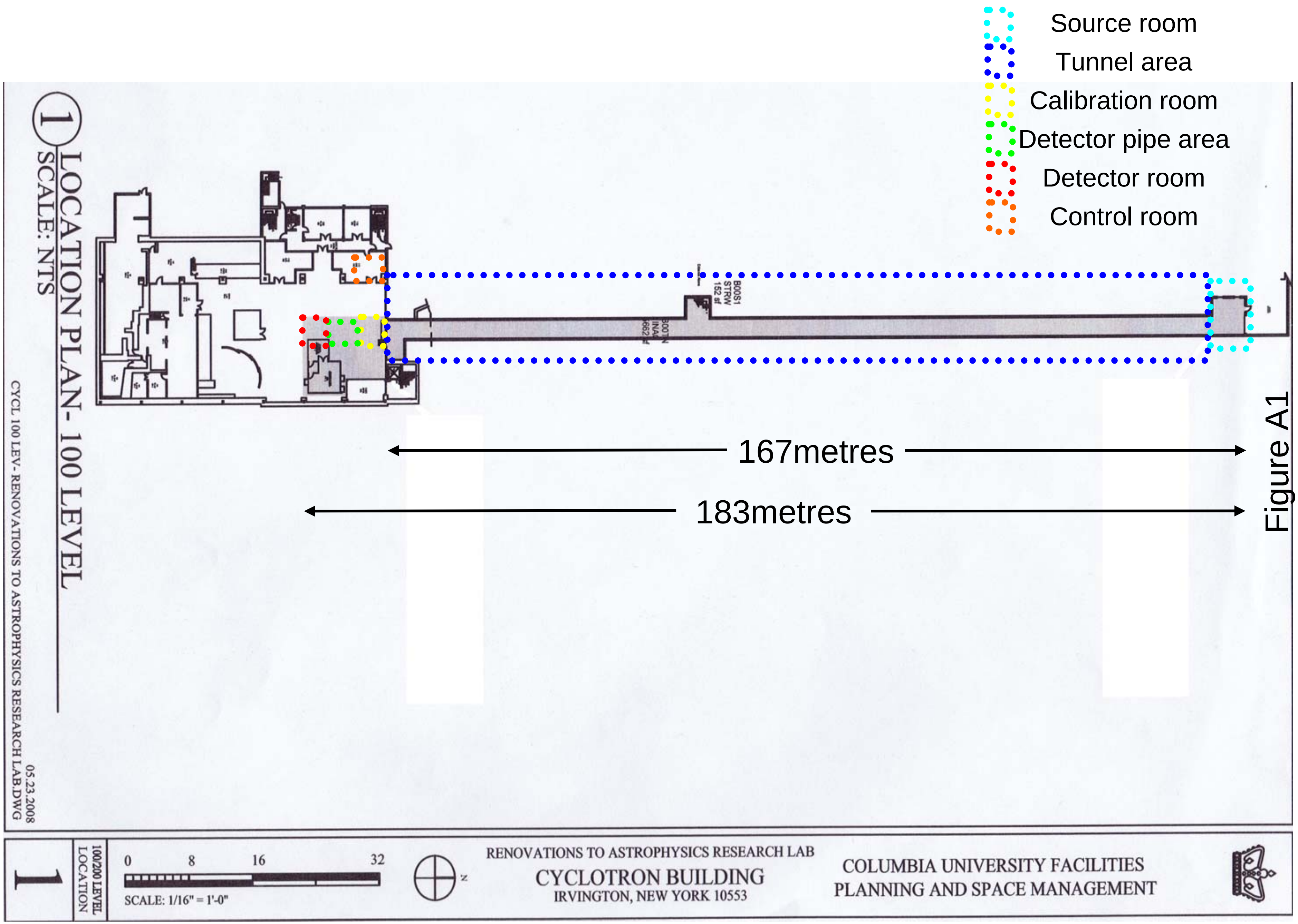

Source room
Tunnel area
Calibration room
Detector pipe area
Detector room
Control room
1
LOCATION PLAN- 100 LEVEL
SCALE: NTS
CYCL 100 LEV- RENOVATIONS TO ASTROPHYSICS RESEARCH LAB.DWG
05.23.2008
167metres
183metres
1
100/200 LEVEL
LOCATION
0
8
16
32
SCALE: 1/16" = 1'-0"
N
RENOVATIONS TO ASTROPHYSICS RESEARCH LAB
CYCLOTRON BUILDING
IRVINGTON, NEW YORK 10553
COLUMBIA UNIVERSITY FACILITIES
PLANNING AND SPACE MANAGEMENT

Figure A1

Interlock + Warning System

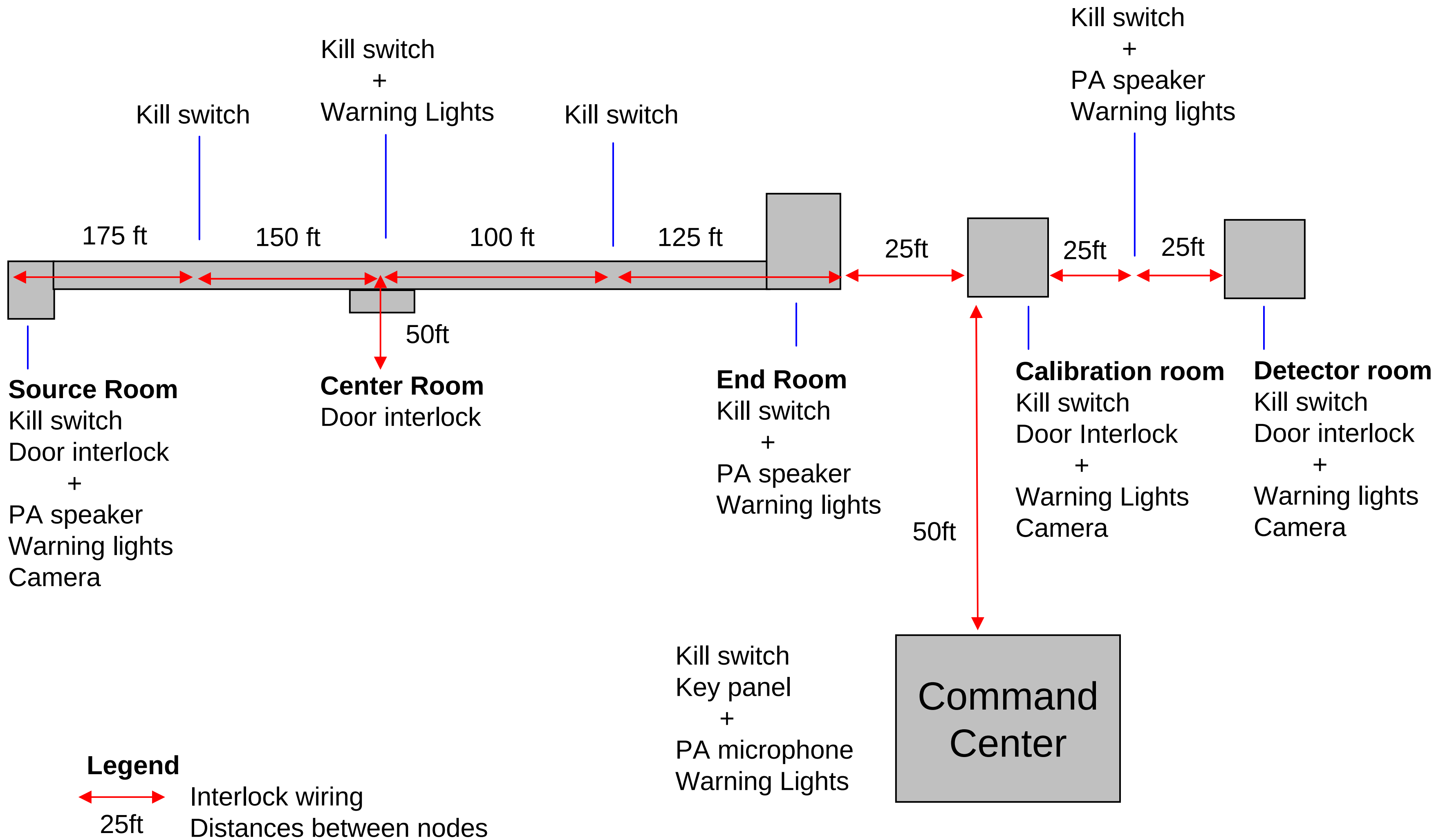


Figure A2

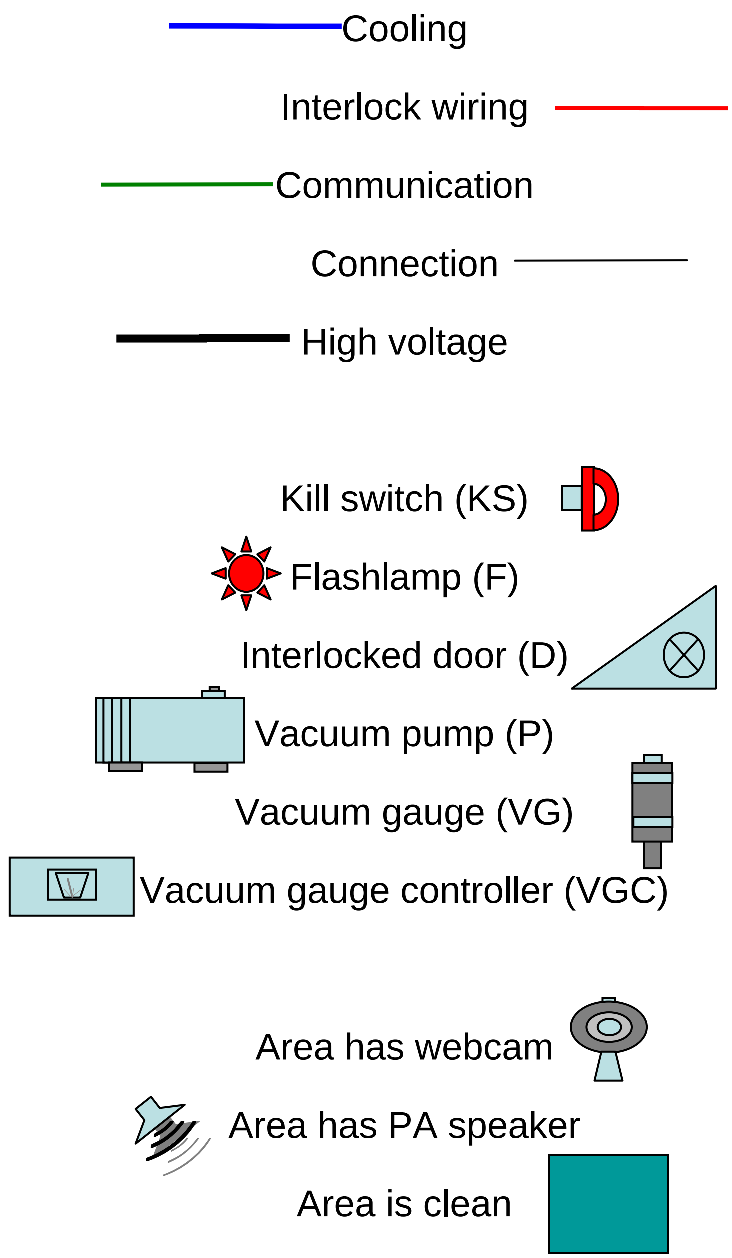

Cooling
Interlock wiring
Communication
Connection
High voltage
Kill switch (KS)
Flashlamp (F)
Interlocked door (D)
Vacuum pump (P)
Vacuum gauge (VG)
Vacuum gauge controller (VGC)
Area has webcam
Area has PA speaker
Area is clean

Figure A3

Control room

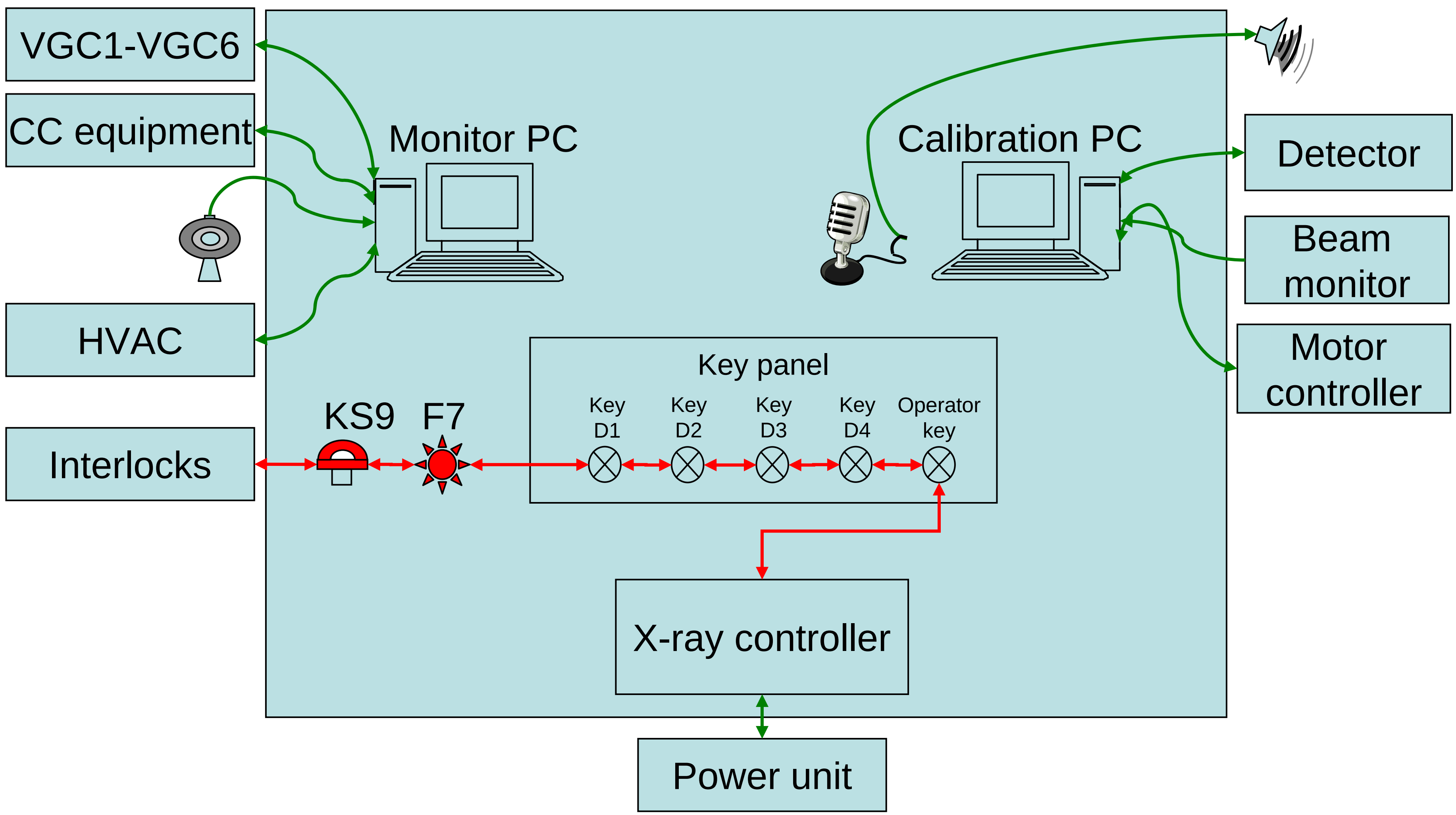


Figure A4

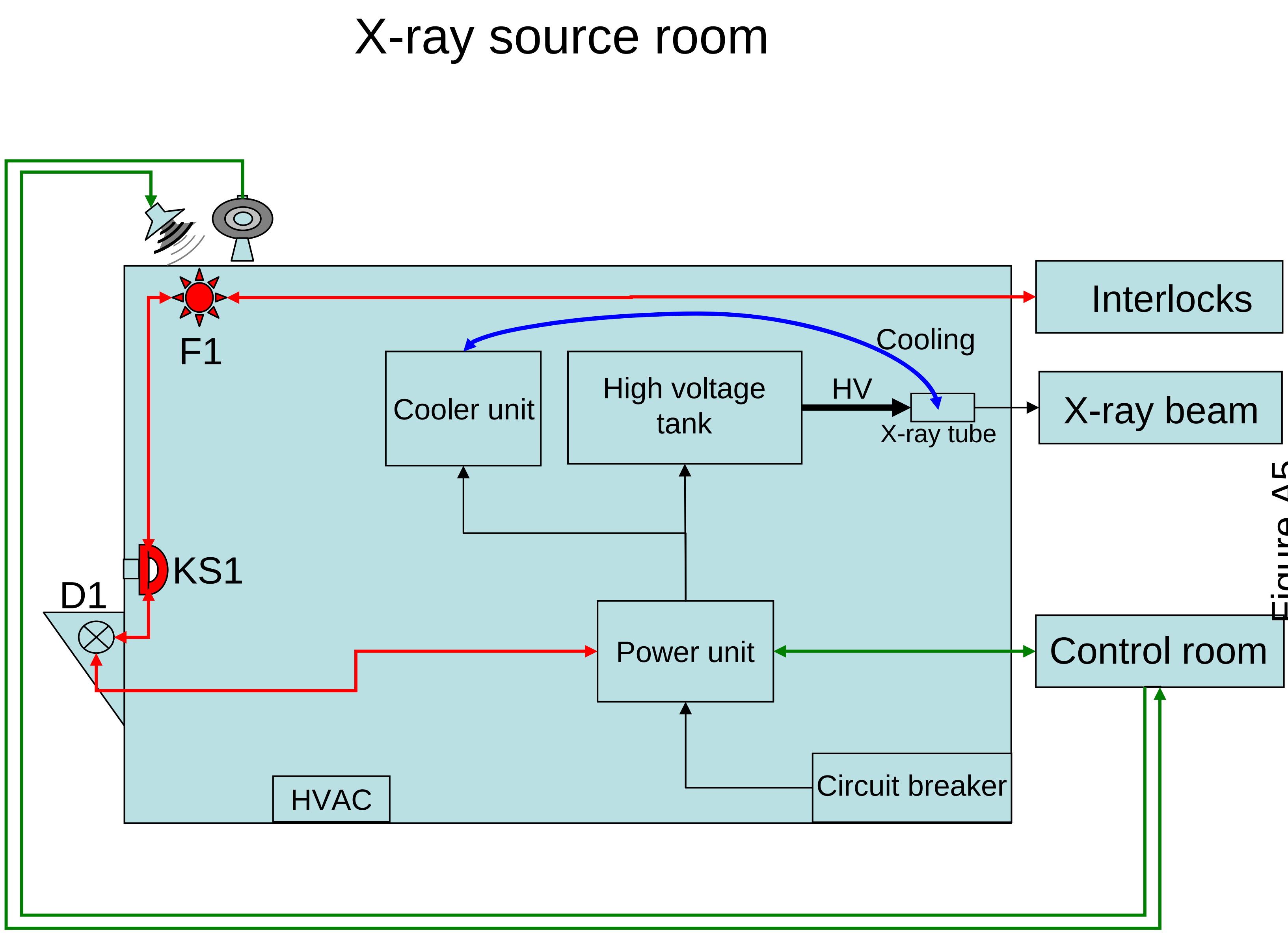

X-ray source room
F1
Cooler unit
High voltage
tank
Cooling
HV
X-ray tube
Interlocks
X-ray beam
KS1
D1
Power unit
Control room
HVAC
Circuit breaker

Figure A5

Tunnel area

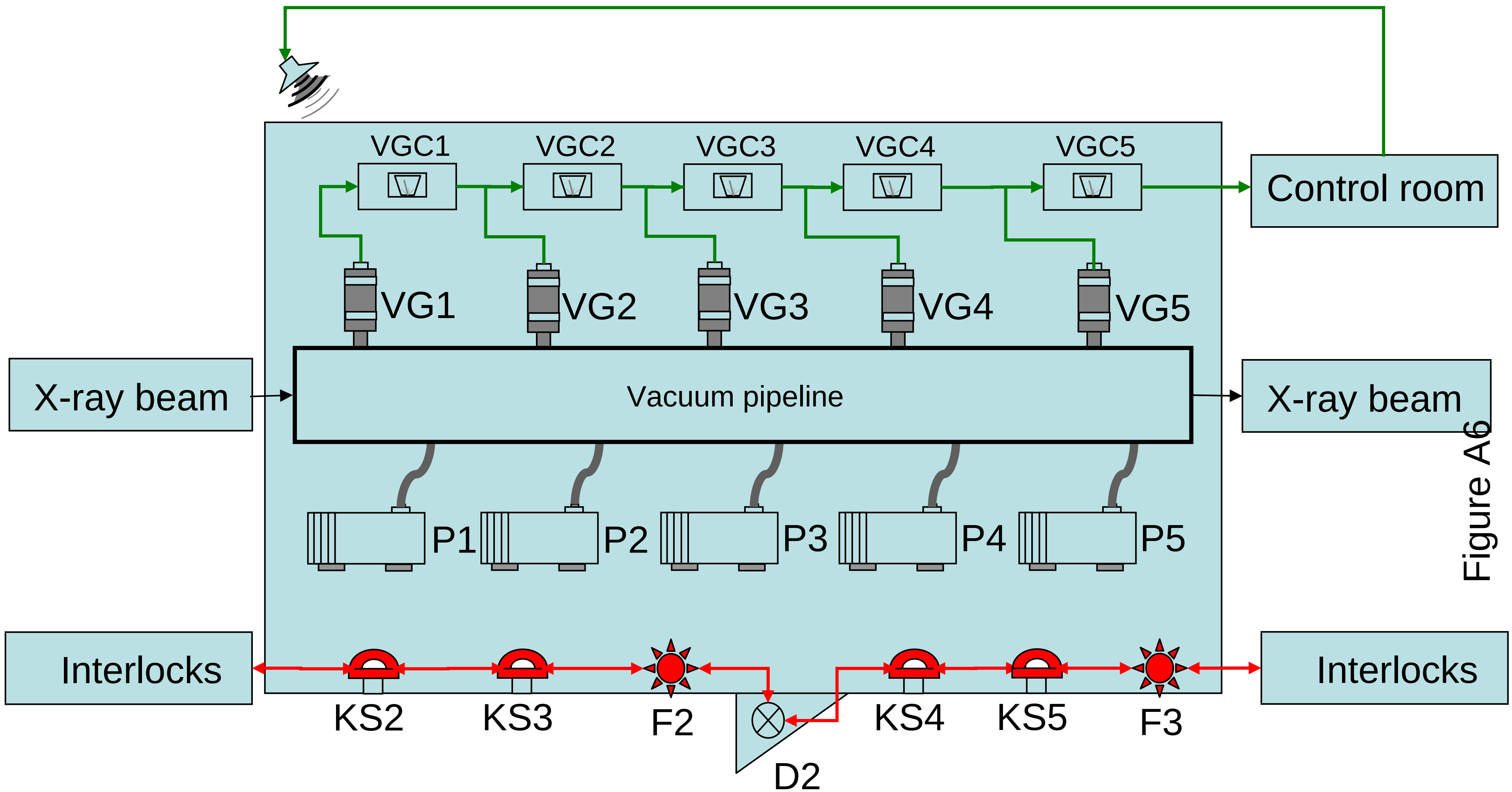


Figure A6

Calibration room

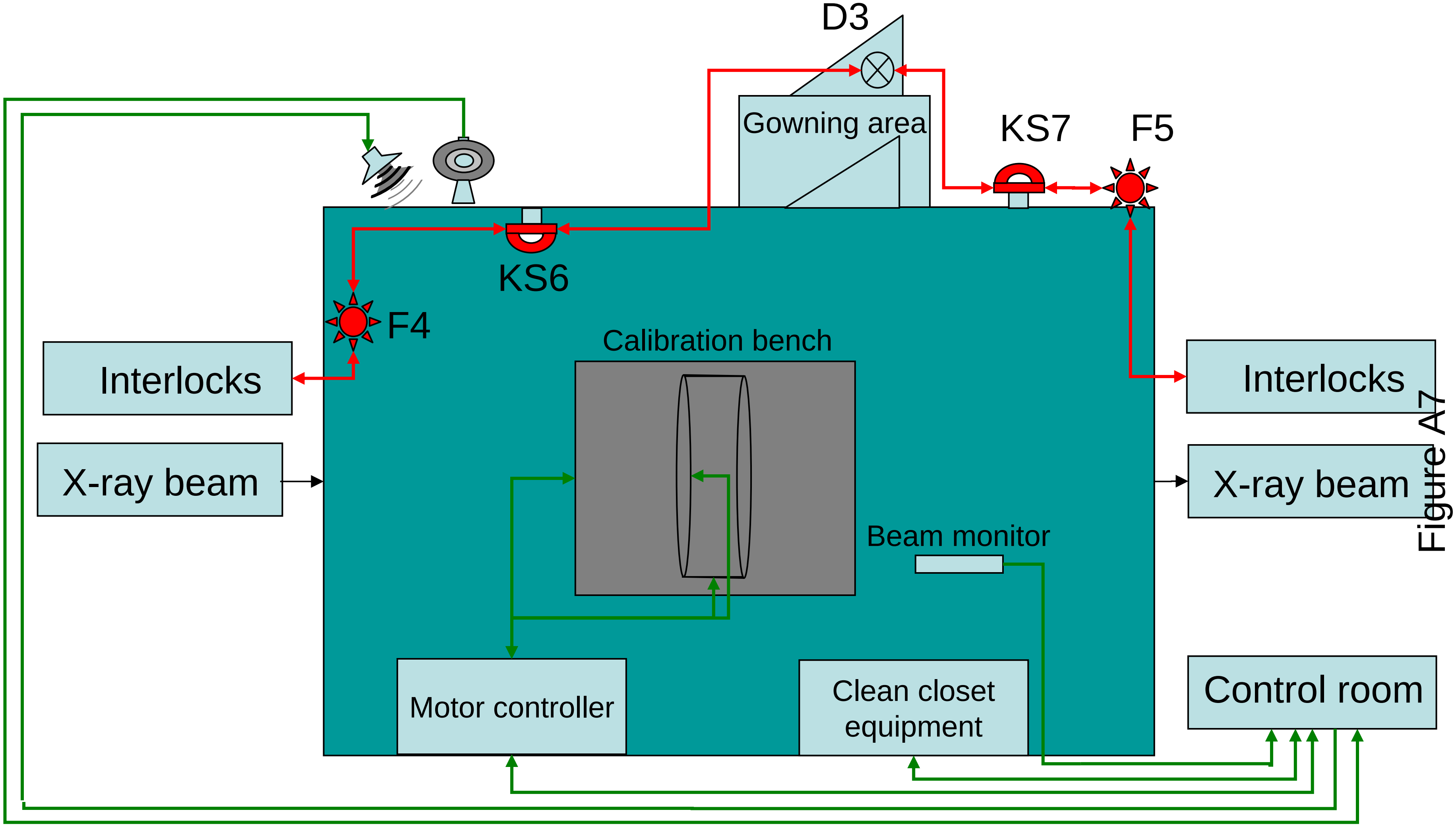


Figure A7

Detector pipe area

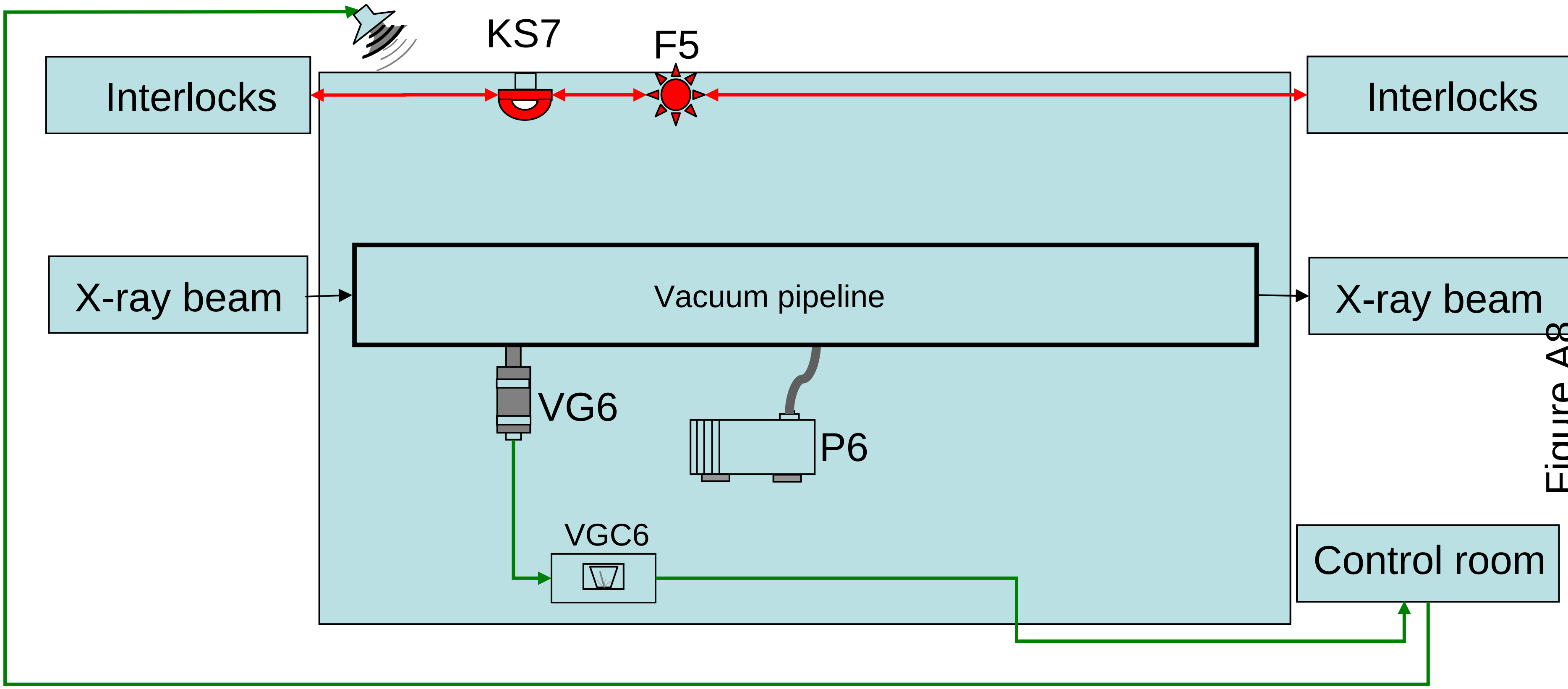


Figure A8

Detector room

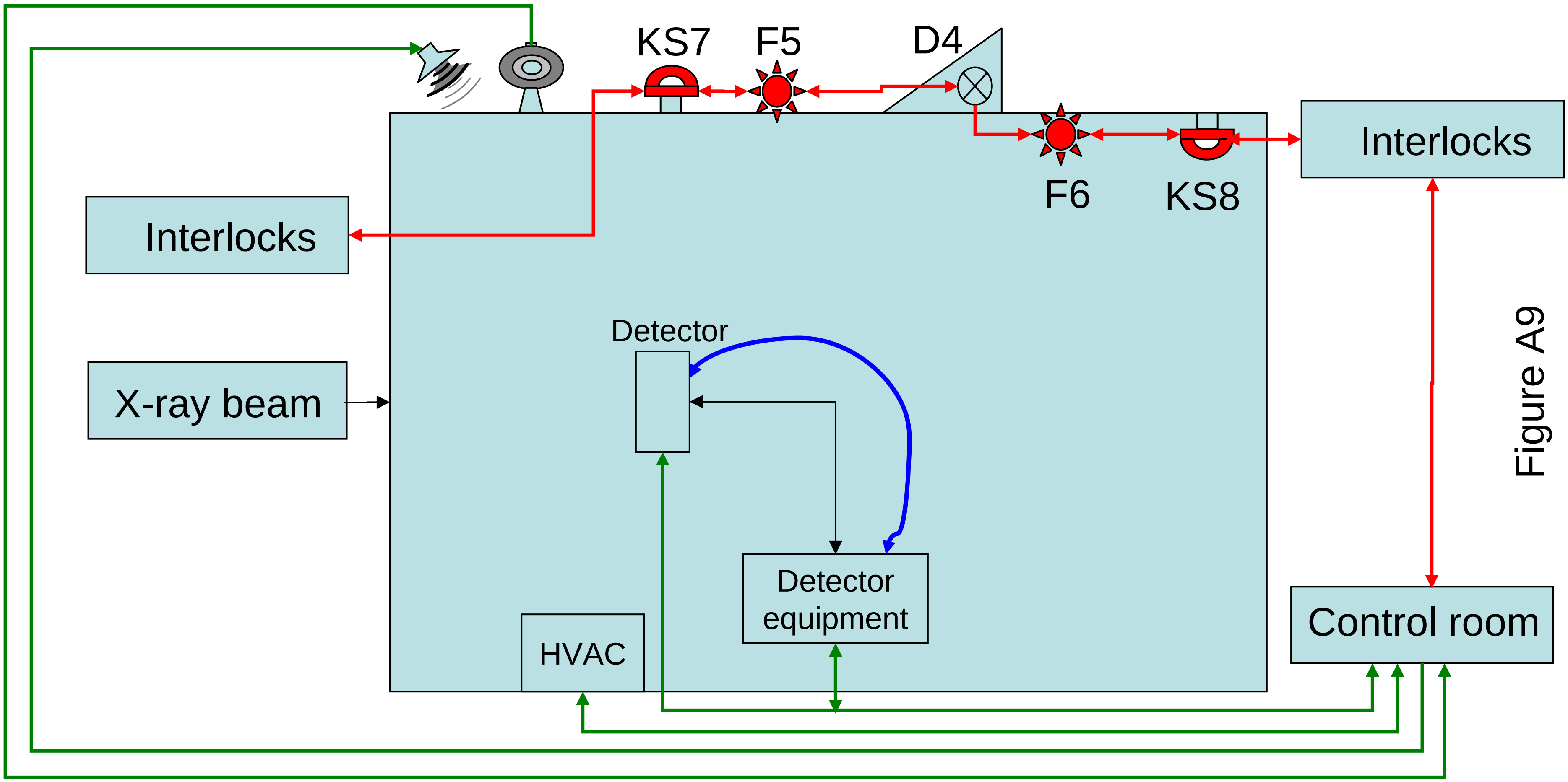
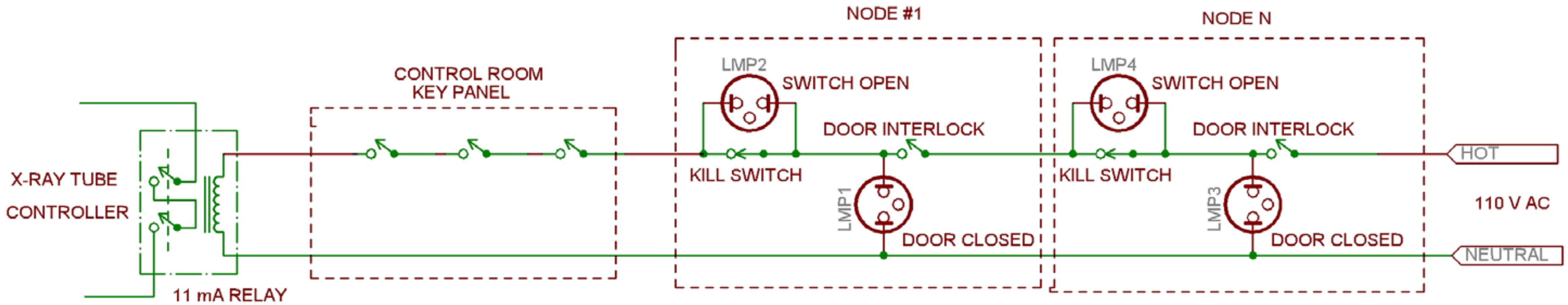
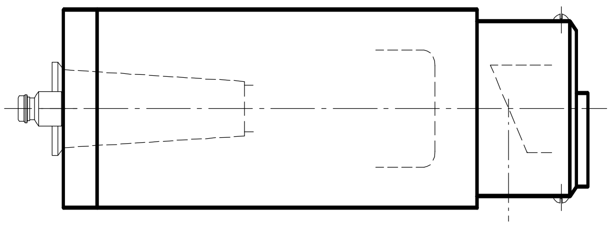


Figure A9



Simplified Interlock
4/12/2009 04:12:47p
Sheet: 1/1



MXR-102

Strahlerdokumentation
Tube Assembly Documentation

Diese Dokumentation ist nur für die folgende Strahlernummer gültig
This documentation is valid only for the following tube assembly no.

Ohne Röhren- bzw. Strahlerschild an dieser Stelle ist die Dokumentation nur zur Orientierung. Änderung ohne Ankündigung möglich.

Without tube or tube assembly label here, the documentation is meant for information only. Modifications without notification possible.

Strahlerbezeichnung
Tube AssemblyType

MXR-102

Made in Switzerland

Bestellnummer
Reference No.
915343.52

WARNUNG
Dieser Röntgenstrahler enthält keine ausreichende Strahlenschutzabschirmung. Der Strahlenschutz muss durch die Konstruktion des Gerätes sichergestellt werden.
Die Haubendurchlassstrahlung ist grösser als 2.5 mSv/h.
WARNING
This X-ray tube assembly contains no sufficient protective shielding. X-ray protection must be adapted into the design of the equipment.
The leakage radiation is above 2.5 mSv/h.

Der Inhalt dieser Dokumentation muss an den Betreiber der Röntgenröhre bzw. des Röntgenstrahlers weitergegeben werden.
The content of this documentation must be transmitted to the user of the X-ray tube or the X-ray tube assembly.

Dokumentations-Nr. *Documentation No.*	**D2-915343.52**	Ausgabenummer *Revision No*	**D**	Ausgabe-Datum *Date of release*	**2004-10**	**MXR-102**

Originaltext: deutsch
Original Text: German

Inhaltsverzeichnis

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Allgemeine Beschreibung

Der Röntgenstrahler MXR-102 wurde für den Einsatz in der Industrie entwickelt.
Der Strahler besteht aus einer unipolaren Röntgenröhre mit gekühlter Anode auf Erdpotential und einer integrierten Hochspannungssteckdose. Das Strahlenschutzgehäuse ist mit Wasseranschlüssen ausgerüstet.
Die Hauptvorteile sind hohe Leistung, kleine Abmessungen, kleines Gewicht und robuste Konstruktion.

General Description

The X-ray tube assembly MXR-102 has been designed for industrial applications.
The tube assembly consists of a monopolar X-ray tube with cooled anode at ground potential and a high voltage receptacle socket. The tube housing has fittings for water hose connections.
The main advantages are high power, small dimensions, low weight and rugged mechanical design.

Sicherheit

WARNUNG

Die Informationen dieses Kapitels müssen vor Installation und Inbetriebnahme beachtet werden.
Der Gebrauch von Röntgenröhren und Röntgenstrahlern ist mit ernstzunehmenden Risiken verbunden.

Bei der Installation eines Röntgenstrahlers in eine Röntgeneinrichtung und beim Betrieb von Röntgeneinrichtungen sind die am Standort der Anlage gültigen Vorschriften zu beachten.

Einführung

Für den sicheren und zweckmässigen Gebrauch von Röntgenröhren und -strahlern sind Hersteller und Betreiber von Röntgenanlagen verantwortlich.

Röntgenröhren haben keine unbegrenzte Lebensdauer und können gelegentlich Störungen aufweisen, die eine Inspektion oder Reparatur nötig machen. Mehrfache Schutzmassnahmen und Sicherheitsvorkehrungen im Störfall zum Schutz von Personal und Material sind deshalb zu treffen.

Alle Personen, die mit Röntgenstrahlung oder röntgenstrahlenerzeugenden Systemen arbeiten (Inbetriebnahme, Bedienung, Wartung, Reparatur) und dabei der Röntgenstrahlung direkt oder indirekt ausgesetzt sein können, müssen die nötigen Vorkehrungen treffen, um sich und andere zu schützen.

Insbesondere ist die ganze Umgebung röntgenstrahlenerzeugender Systeme abzusichern.
Nur genügend qualifiziertes und erfahrenes Personal, welches mit den lokalen und nationalen Vorschriften über den Betrieb von röntgenstrahlenerzeugenden Systemen vertraut ist, darf für Betrieb, Wartung und Reparatur des Systems betraut werden.

Hochspannung

Röntgenröhren und -geräte arbeiten mit sehr hohen Spannungen, die lebensgefährlich sind. Röntgenanlagen müssen deshalb so konzipiert sein, dass das Personal nicht mit der Hochspannung in Berührung kommen kann.

Safety

WARNING

The information contained in this section must be read prior to installation and first operation.
Serious hazards exist in the operation of X-ray tubes and tube assemblies.

When installing an X-ray tube assembly into an X-ray equipment and/or operating an X-ray equipment, compliance with local regulatory requirements must be assured.

Introduction

The safe and purposeful operation of X-ray tubes and tube assemblies is within the responsibility of both the X-ray equipment manufacturer and the user.

X-ray tubes do not have an indefinite life and can suffer from perturbations that may necessitate inspection and repair. Multiple protective measures and safeguards should thus be taken to ensure protection of personnel and material.

All personnel working with X-ray-producing systems (installing, operating, maintaining, repairing), and those persons who may be exposed to X-ray either directly or indirectly, must take the necessary precautionary measures to protect themselves and others.

In particular the entire area of such X-ray-producing systems must be protected.
Only qualified and experienced personnel, who are fully conversant with local and national regulations concerning the operation of X-ray production systems should be permitted to operate, maintain or repair the system.

High Voltage

X-ray tubes and X-ray equipment operate at voltage levels which are potentially life threatening. X-ray equipment must therefore be designed to prevent personnel from coming into contact with high voltage.

Warntafeln betreffend Hochspannung müssen fest an der Anlage angebracht sein.
Wird ein direkter Zugang zum Röntgenstrahler nötig, ist zuerst die Stromzufuhr zum Primärkreis zu unterbrechen, dann sind Hochspannungskondensator und -kabel zu entladen.

Prominently displayed high voltage warning signs must also be firmly attached to the equipment.
When direct access to the X-ray tube assembly is necessary, first interrupt the primary circuits of the power supply, then discharge the high voltage capacitors and cable.

Röntgenstrahlung

X-Radiation

Allgemein

Röntgenröhren und -strahler produzieren Röntgenstrahlen, sobald Hochspannung angelegt ist. Betriebspersonal und Nichtbetriebspersonal müssen mit geeigneter Abschirmung von der Röntgenstrahlung und vor der Streustrahlung geschützt werden.

General

X-ray tubes and tube assemblies produce X-rays when high voltage is applied. Operating personnel and non-operating personnel must be protected by appropriate shielding against radiation from both the main X-ray beam and scattered radiation.

Strahlenschutz

Achtung: Dieser Röntgenstrahler hat keine ausreichende interne Strahlenschutzverkleidung.

Beim Einbau in ein Röntgengerät müssen lokale und nationale Strahlenschutznormen und Vorschriften eingehalten werden.

X-Ray Protection

Caution: This X-ray tube assembly does not contain sufficient internal radiation protection.

Local and National Radiation Protection Standards must be adhered to as regards to X-ray protection of the system and its environment.

Röhrenwechsel / Änderungen

Nach jedem Röhrenwechsel, jeder Reparatur oder Änderung am Gerät ist die Wirksamkeit des Strahlenschutzes zu überprüfen.

Tube Exchange / Alterations

A reconfirmation of the radiation protection integrity should be performed after each tube exchange, repair, modification, or upgrade of the unit.

Strahlenkollimatoren

Um nicht genutzte Röntgenstrahlung einzuschränken, müssen Strahlenkollimatoren unter Berücksichtigung der lokalen und nationalen Vorschriften eingesetzt werden.

X-ray Beam Collimators

In order to reduce unnecessary X-rays, a beam collimator must be used in accordance with local and national regulations.

Strahlenfilter

Die Röntgenröhren bzw. -strahler werden ohne Zusatzfilter geliefert. Beim Einbau in das Röntgengerät muss die Gesamtfilterung den am Standort gültigen Vorschriften angepasst werden.

X-Ray Filter

Tubes are delivered without additional filters on the output window. On mounting tubes into the X-ray equipment, the total filtration values must be in compliance with the local requirements and regulations.

Kühlung

Die Funktionstüchtigkeit der Kontrollelemente des Kühlflusses und der Sicherheitsschalter muss durch regelmässige Kontrollen sichergestellt werden.
Im Fall von Sicherheitsabschaltungen müssen die Gründe dafür sorgfältig ermittelt und entsprechende Korrekturen vorgenommen werden.

Cooling

Regular checks and maintenance work should be undertaken on cooling flow control elements and safety cut-out switches.
In case of the occurrence of safety related shut-off, the reasons for the shut-off should be carefully determined and corrected accordingly.

Beryllium-Fenster der Röhre

Die Röhre ist mit einem Berylliumfenster im Strahlengang ausgerüstet. Das Einatmen von Berylliumdämpfen oder -staub ist gefährlich. Es wird deshalb empfohlen
- das Fenster vor Flüssigkeiten und Dämpfen so gut wie möglich zu schützen, um so dessen Korrosion zu reduzieren,
- vorhandene Korrosionssalze auf dem Beryllium-Fenster weder wegzukratzen noch anders zu entfernen.

Am Ende der Röhrennutzungsdauer muss das Beryllium-Fenster gemäss lokalen und nationalen Vorschriften entsorgt werden. Die Röhre kann zur Entsorgung an den Hersteller zurückgeschickt werden (Preis für Entsorgung auf Anfrage).

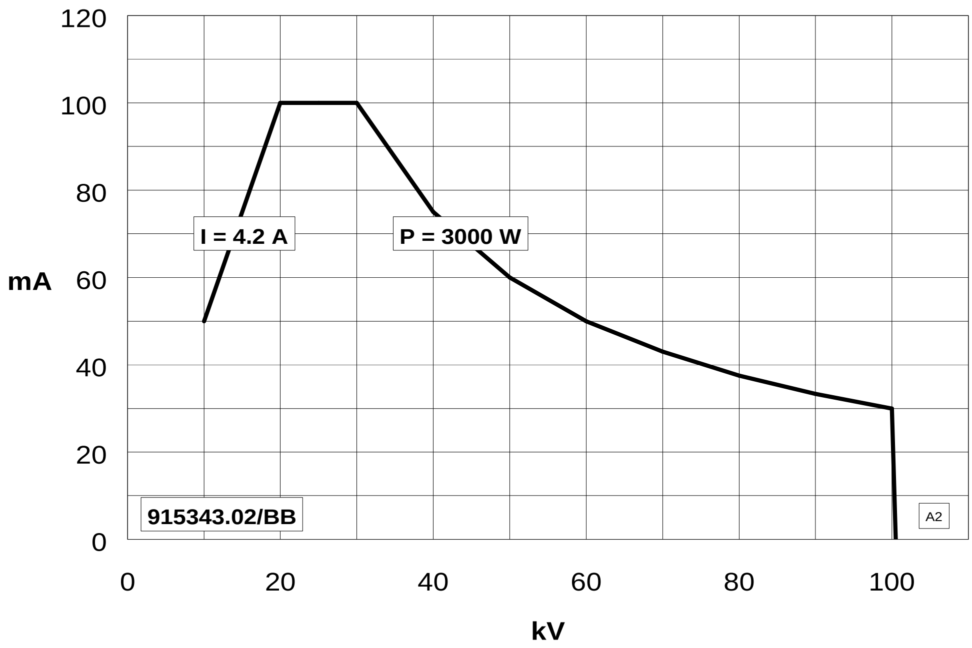
Beryllium Window of the Tube Insert

The X-ray tube is equipped with a beryllium window. Fumes of beryllium metal (or its compounds) or particles can be hazardous if inhaled. It is therefore advised that
- the window be protected as much as possible from fluids and vapours in order to prevent corrosion of the window.
- if there are corrosion salts on the Beryllium window they should not be scraped or machined off.
At the end of the tube’s life, the Beryllium window must be disposed off in accordance with local and national regulations or the tube may be returned to the tube manufacturer. (Price for disposal on request.)

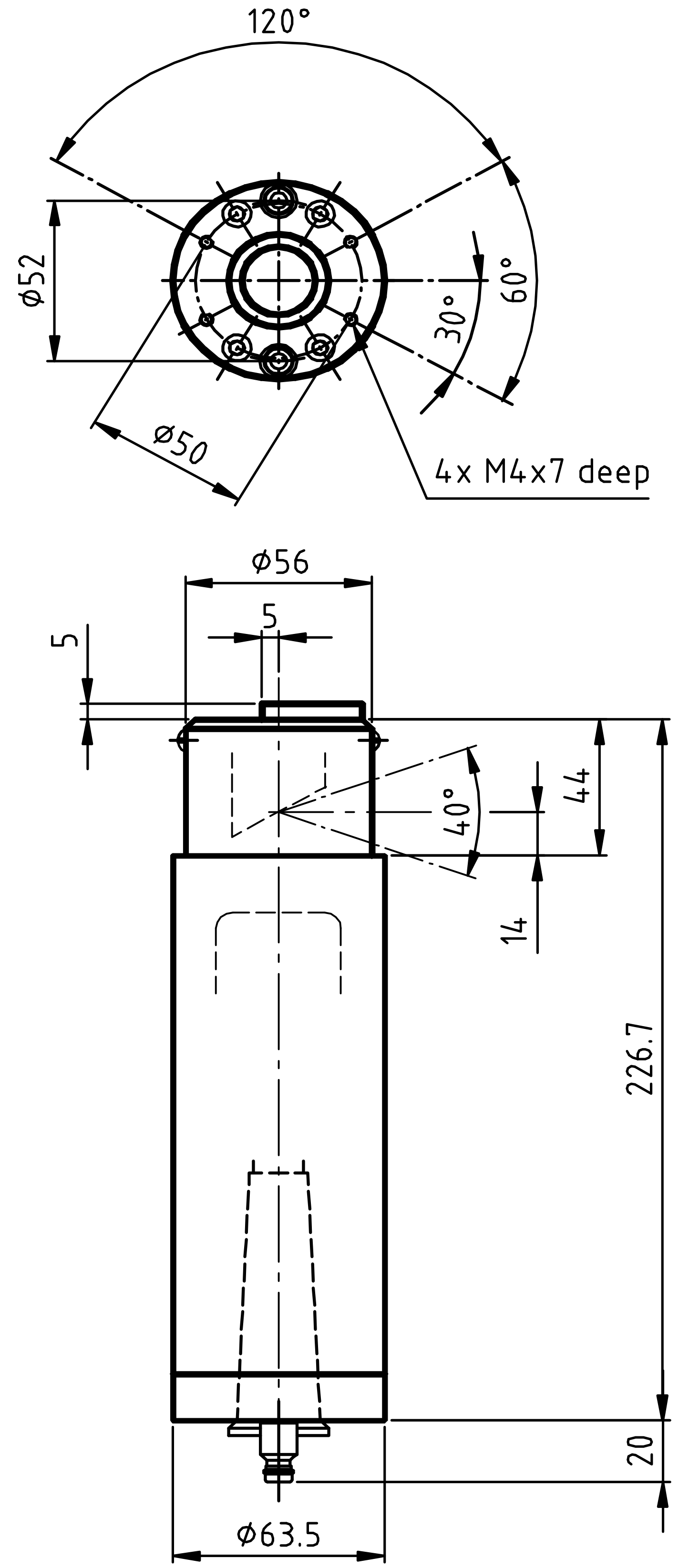
Spezifikationen *Specifications*

Strahlertyp **Tube Assembly Type**	**MXR-102**
Röhrentyp Tube Insert Type	MIR-102
Haubentyp Tube Housing Type	MOR-101
Röntgenröhren-Nennspannung Nominal X-ray tube voltage	100 kV
Dauerleistung Continuous rating	3000 W
Röhrenstrom bei Nennspannung, max. Tube current at nominal voltage, max.	30 mA
Optischer Brennfleck nach EN 12543 (bei 1 kW) Focal spot acc. EN 12543 (at 1 kW)	d = 5.5 mm
Heizstrom, max. Filament current, max.	4.2 A
Heizspannung bei max. Heizstrom, typisch Filament voltage at max. filament current, typical	7.5 V
Eigenfilterwert Inherent filtration	0.8 ± 0.1 mm Be
Targetmaterial Target material	W
Targetneigungswinkel Target angle	30°
Strahlenbündel Radiation coverage	40°
Kühlmittel Cooling medium	Wasser Water
Kühlmitteldurchfluss, min. Cooling medium flow, min.	4 l/min
zulässiger Druck am Kühlmitteleingang, max. Pressure at cooling medium inlet, max.	6 bar
zulässige Temperatur am Kühlmittel-Eingang, max. Cooling medium temperature at cooling medium inlet, max.	35°C
Masse ca. Mass app.	3.5 kg
Steckertyp Terminal type	R10

Leistungskurve *Rating Chart*



Abmessungen *Dimensions*



Zubehör

Accessories

	Bestellnummer *Reference No.*	
Wasseranschlusskupplung d=8mm	633117	*Fitting for water hose connections d=8mm*
Hochspannungskabel R10/R24 (x = Länge in m)	U3/100-R10-R24-xxm	*High voltage cable R10/R24 (x = length in m)*
Kabelflansch	651142	*Mounting flange*

Allgemeine Betriebshinweise

Allgemeines

Die Steuerung der Hochspannung und des Heizstroms sowie die Auslegung des Kühlsystems liegen in der Verantwortung des Geräteherstellers.

Aus Sicherheitsgründen sind folgende Abschaltarten vorzusehen:

- Standardabschaltung am Ende der Aufnahme bzw. des Gebrauchs der Anlage
- Notabschaltung aus betrieblichen Gründen
- Notabschaltung wegen mangelnder Kühlung oder aus anderen technischen Gründen.

Hochspannungsanschluss

Hochspannung und Heizfadenstrom werden durch ein Hochspannungskabel mit folgenden Spezifikationen zugeführt:

Steckertyp: R10

Anschlüsse der Heizwendel: (C=Masse)

Operation

General

The control of the high voltage and the filament current as well as the design of the cooling system are the responsibility of the equipment manufacturer.

For safety reasons the power must be switched off under the following circumstances:

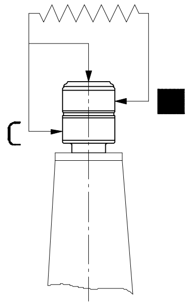
- *standard shut-off at the end of an exposure or at the end of the use of the equipment*
- *emergency cut-out for operational reasons*
- *emergency cut-out due to insufficient cooling or due to other technical reasons.*

High Voltage Connection

High voltage and filament current are supplied by the high voltage cable with the following specifications:

Terminal type: R10

Connection of filament: (C=Common)



Das Hochspannungskabel wird mit einem Kabelflansch am Strahler angeschlossen.

Der sachgerechte Anschluss von Hochspannungskabeln ist im Kapitel "Anleitung zur Montage und Inbetriebnahme" beschrieben.

The high voltage cables are mounted to the tube assembly with a mounting flange.

The appropriate mounting of the high voltage cables is described in the chapter " Installation and Operation Instructions".

Überspannung, Überstrom

Auf keinen Fall dürfen die maximalen Betriebsdaten der Röhre (d.h. Filamentstrom, Röhrenstrom und Röhrenspannung) überschritten werden, da sonst die Röhre Schaden nehmen kann.

Dämpfungswiderstände im Hochspannungskreis von wenigstens 100 kOhm sowie Abschaltelemente bei Überstrom und Überspannung sind ein notwendiger Schutz der Röhre.

Overvoltage, Overcurrent

Under no circumstances should the maximum operating parameters of the tube (i.e. filament current, tube current and voltage) be exceeded, otherwise the tube may be damaged.

Therefore a damping resistor of at least 100 kOhm in the high voltage circuit and trip devices for overcurrent and overvoltage in the control circuit must be provided.

Heizstrom während Betriebspausen

Während Betriebspausen sollte der Heizstrom reduziert oder abgeschaltet werden. Hohe Heizströme können zur Verkürzung der Lebensdauer des Heizfadens führen.

Entsprechende Vorkehrungen in der Steuereinheit werden empfohlen.

Filament Current during Standby Periods

During standby periods the filament current should be reduced or switched off. High filament currents can result in the reduction of the filament lifetime.

The appropriate design of the control unit to achieve this is recommended.

Kühlung der Anode

Generell

Das Kühlsystem ist nicht Bestandteil des Lieferumfangs. Es ist sicherzustellen, dass der Kühlmittelfluss die Anforderungen an die Anodenkühlung erfüllt.

Mangelnde Kühlung kann zur Zerstörung der Anode führen. Deshalb muss die Kühlung unbedingt vor dem Anlegen der Hochspannung eingeschaltet werden.

Cooling of the Anode

General

The cooling system is not supplied by COMET. The customer should ensure that the cooling medium flow meets the required cooling conditions.

Insufficient cooling can lead to the destruction of the anode. Therefore cooling must be switched on prior to the application of the high voltage.

Kühlmittelüberwachung

Druck, Durchflussmenge und Temperatur beim Kühlmitteleingang in den Strahler müssen mit geeigneten Mitteln überwacht werden.
Bei Unterschreitung des minimalen Drucks, der minimalen Durchflussmenge bzw. beim Überschreiten der maximalen Temperatur ist die Hochspannung sofort zu unterbrechen.
Ein sicherer Betrieb der Röhre bzw. des Strahlers kann nur dann garantiert werden, wenn die spezifizierten Werte für die Kühlung eingehalten werden

Das Kühlsystem sollte mit Sicherheitsschaltern für Druck, Durchfluss und Temperatur des Kühlmittels ausgerüstet sein.
Wir empfehlen, die Überwachungssysteme bei der Inbetriebnahme auf ihre Funktionstüchtigkeit hin zu überprüfen.

Zum Schutz des Strahlers sollte die Kühlung nach Abschaltung der Anlage noch mindestens 2 Minuten weiter betrieben werden.
Das gilt auch bei Notabschaltungen der Anlage wegen Überspannung, Überstrom oder Überhitzung.
Im Falle von Überhitzung im Anodenbereich muss der Strahlenschutz auf seine Wirksamkeit hin überprüft werden.

Röhre und Strahler sind vor dem Service bzw. der Wartung abzukühlen. Bevor das Kühlmittel Raumtemperatur erreicht hat, sollten keine Wartungsarbeiten ausgeführt werden.

Control of Cooling medium

Pressure, flow, and temperature of the cooling medium at the inlet to the tube or the tube assembly must be appropriately monitored.
High voltage must be interrupted when the pressure or flow rate fall fall below the minimum level or when the temperature exceeds the maximum level allowed.

Safe operation of the tube or the tube assembly can only be guaranteed if it is used in accordance with the cooling specifications given in this documentation.

The cooling system should be equipped with safety switches for pressure, flow, and temperature of the cooling medium.
We recommend strongly to test these control devices before starting the operation of the equipment.

When the tube is switched off, the coolant flow must continue for at least 2 minutes in order to protect the anode and the lead protection from overheating.
This is also the case after emergency shut down after overvoltage, overcurrent or overheating.
After such a shut-down, the X-ray protection of the tube assembly must be carefully checked.

Allow the tube or tube assembly to cool before service or maintenance. No maintenance should be attempted until the cooling medium is at ambient temperature.

Betrieb in besonderen Umgebungsbedingungen

Beim Betrieb in einer Umgebung mit aggressiven Medien und/ oder starken Vibrationen sind Massnahmen zum Schutz der Röhre bzw. des Strahlers zu treffen. Die Rücksprache mit dem Hersteller wird empfohlen.

Aggressive Environmental Conditions

Operation in an environment with aggressive media and/or strong vibrations requires appropriate measures. Consultation with the manufacturer of the tube assembly is recommended.

Reinigung

Für generelle Reinigungszwecke des Strahlengehäuses sind möglichst lösungsmittelfreie Produkte zu verwenden. Auf jeden Fall muss vermieden werden, dass Lösungsmittel auf das Strahlerfenster oder in die Hochspannungssteckdose gelangt.

Auch zur Reinigung der inneren Teile der Hochspannungsstecker dürfen keine Lösungsmittel verwendet werden. Diese Teile sind mit trockenem, saugfähigem und nicht faserndem Papier von Fettresten zu befreien. Auf keinem Fall darf der Strahler zur Reinigung der Röhre zerlegt werden.

Cleaning

For the general cleaning of tube housing, non-solvent based products are perfectly adequate. Avoid using solvents on the tube assembly window and do not use solvents to clean the inside of the high voltage cable termination plug.

Detergents should be used very sparingly in the region of the high voltage cable termination plug to avoid damaging the grease between the receptacle and the cable terminal. In no case should the tube assembly be disassembled to clean the X-ray tube insert.

Anleitung zur Montage und Inbetriebnahme

Anschluss des Strahlers

Bei Verwendung von COMET Kabeln ist wie unten beschrieben vorzugehen, bei Fremdkabeln sinngemäss. Grundsätzlich sind die Angaben der Kabelhersteller zu beachten.

Zunächst wird die Hochspannungssteckdose mit einem trockenen, nicht fasernden Papier gereinigt. Lösungsmittel sind zu vermeiden, da sie die innere Oberfläche der Hochspannungssteckdose angreifen können.

Auch die metallischen Kontakte des Kabels sind sorgfältig zu reinigen und zu prüfen. Schlechte Kontaktierung kann die Röhre beschädigen.

Es ist wichtig, dass der Kabelanschluss sorgfältig vorgenommen wird.

Instructions for Installation and Operation

Connection of the Tube Assembly

The instructions below refer to cables supplied by COMET. For other cables the procedure will be similar. In any case the recommendations of the cable supplier should be observed.

At first the socket of the receptacle has to be carefully cleaned with lintfree paper. Don't use solvents, they may attack the surface of the socket.

The metal contacts have to be cleaned carefully and their alignement to be checked. Bad contacts may damage the tube.

It is important that the connection of the cable is made very carefully.

Der Kabelanschluss muss innerhalb der Hochspannungssteckdose unter festem Druck stehen. Um diesen Druck zu justieren, wird das trockene, ungefettete Kabel zuerst vorsichtig und parallel zur Achse der Hochspannungssteckdose bis zum Anschlag eingeführt.

Der definitive Druck wird wie folgt eingestellt:

Kabelflansch drehen bis zwischen ihm und der Röhre ein Spalt von 3 bis 4mm besteht.

Der Stecker wird nun wieder herausgezogen. Die Steckdose und der Stecker werden mit dem mitgelieferten Hochspannungsisolierfett vorsichtig eingefettet.

Der gefetteten Kabelstecker wird nun parallel zur Achse der Hochspannungssteckdose bis zum Anschlag eingeführt.

Der Kabelflansch ist mit den entsprechenden Befestigungsschrauben an dem Strahlenschutzgehäuse zu fixieren. Dabei ist sicherzustellen, dass der Kabelflansch nicht aus seiner voreingestellten Position gedreht wird.

Beim Anschliessen des Kühlsystems ist auf die durch Pfeile angegebene Fliessrichtung zu achten.

The cable terminal plug must be under firm compression within the high voltage receptacle socket. To adjust this compression, first introduce the dry, non-greased cable carefully and parallely to the axis of the receptacle socket, advancing it until it stops.

The definitive compression is set up as follows:

Rotate the mounting flange until there is a gap of 3 to 4 mm between the mounting flange and the tube.

Remove the cable plug. The cable plug should be carefully greased using the supplied high voltage insulating grease.

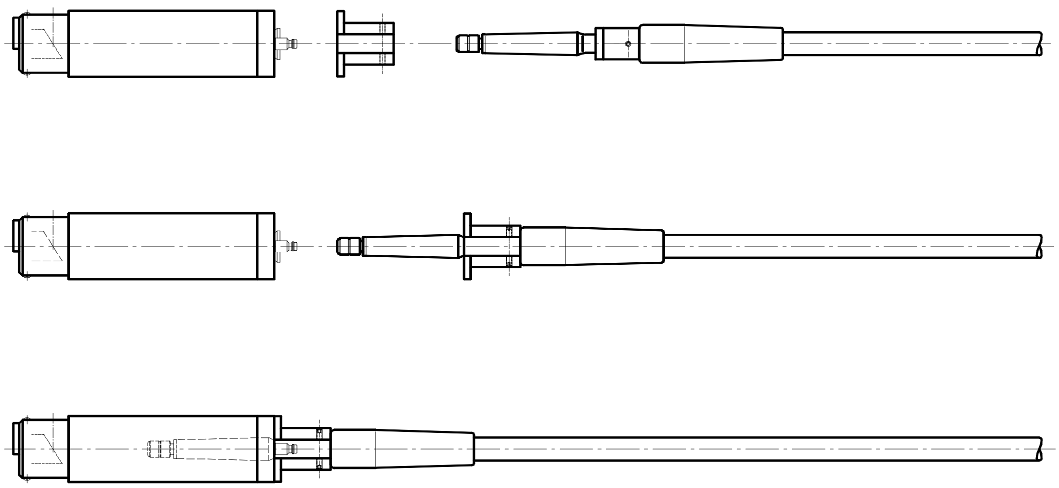
Introduce the greased terminal plug again parallel to the axis of the high voltage receptacle socket and advance until it stops.

Fasten the mounting flange to the tube housing using the flange fastening screws. Make sure not to rotate the mounting flange from its setup position.

Connecting the cooling system make sure the coolant flow is in the direction indicated by the arrows.

Hochspannungsanschluss mit Kabelflansch

High voltage connection with mounting flange



Inbetriebnahme des Strahlers

Kühlung

Vor jeder Inbetriebnahme der Röhre muss die Kühlung eingeschaltet werden. Es muss sichergestellt sein, dass Kühlmittelfluss und Kühlmitteltemperatur den Vorgaben entsprechen.

Einfahren der Röhre

Vor der ersten Inbetriebnahme und nach längeren Betriebsunterbrüchen (mehr als 4 Wochen) muss die Röhre eingefahren werden.

Es wird empfohlen, dafür die Hochspannung von 50 kV in Stufen von 10 kV alle 5 min zu erhöhen, bis die gewünschte Betriebsspannung erreicht ist.

Beim täglichen Einschalten sollte die Spannung von 50 kV in Stufen von 10 kV pro 1 min bis zur gewünschten Betriebsspannung hochgefahren werden.

Dabei sollten Strom und Spannung nicht über die vorgesehenen Betriebswerte hinaus eingestellt werden.

Die Einfahrprogramme dürfen nicht bei voller Leistung gefahren werden. Auf keinen Fall dürfen dabei die maximalen Betriebsparameter überschritten werden.

Nach Abschaltung der Anlage muss die Kühlung noch ca. 2 Minuten nachlaufen, bis die Röhre abgeküht ist.

Eine Strahlenschutzüberprüfung gehört zur Inbetriebnahme nach der Montage.

Initial Operation of the Tube

Cooling

Prior to operating the tube the coolant should be turned on. Make sure that the coolant flow meets the required cooling conditions.

Seasoning and Daily Warm-Up

The tube should be seasoned before placing it into operation for the first time as well as after long down time period (more than 4 weeks).

We recommend that the high voltage is switched on at 50 kV and increased in steps of 10 kV every 5 min until the anticipated operating voltage is reached.

For daily warm-up the voltage should be increased from 50 kV in steps of 10 kV per 1 min up to the desired operating voltage.

Do not to season or warm-up the tube beyond the voltage and current required for the application.

The seasoning and warm-up should not be done at full power, and under no circumstances should the maximum operating parameters of the tube be exceeded.

The cooling system must remain in operation for at least 2 minutes after the termination of the last exposure.

A confirmation of the X-ray protection is part of the initial operation after mounting.

Wartung

Ueberprüfung und Nachjustierung der Hochspannungskabelanschlüsse

Da das Gummikonusmaterial des Hochspannungskabels fliesst und somit durch die Warm-Kalt-Zyklen die Vorspannung verlieren kann, ist die Hochspannungsverbindung periodisch (Empfehlung ca. 6 Monate) zu kontrollieren. Dazu muss das Kabel demontiert, neu eingestellt und gefettet werden.

Neue Kabel sind bei der ersten Inbetriebnahme bereits nach 1-2 Tagen nachzustellen. Grundsätzlich sind die Angaben der Kabellieferanten zu beachten.

Reparatur des Strahlers

Reparaturen des Strahlers bedürfen spezieller Ausrüstungen und Prüfgeräte und sollten nur durch den Hersteller des Strahlers durchgeführt werden.

Maintenance

Checking and Readjustment of the High Voltage Cable Connections

As the rubber cone material of the high voltage cable is deformable and may therefore lose the tension due to the warm/cold cycles, the high voltage connection must be checked periodically (recommendation: 6 months). This is accomplished by disassembling, adjusting, and greasing the cable terminal again.

New cables have to be readjusted already after 1-2 days of their operation. Please refer to the recommendations of the cable supplier.

Repair of the Tube Assembly

Repair of the tube assembly needs special tools and test equipment; it should therefore be executed only by the manufacturer of the tube assembly.

Lagerung und Transport

Allgemein

Nach Abschaltung der Hochspannung sind die Kabel und damit auch die Hochspannungskondensatoren des Generators durch Verbinden der Leiter mit Erdpotential zu entladen, damit die Kabel ohne Gefahr berührt werden können.

Für Lagerung und Transport von Röntgenröhren und Röntgenstrahlern ist vorzugsweise die mitgelieferte Originalverpackung zu verwenden.

Dabei sind die Hochspannungssteckdosen mit den in der Lieferung enthaltenen Plastikdeckeln abzudecken. Dadurch wird die Sauberkeit der Hochspannungssteckdosen gewährleistet.

Wird das Gerät während längerer Zeit nicht benützt, ist das restliche Kühlmittel aus dem Kühlungssystem zu entfernen. Dazu wird während einiger Sekunden Pressluft mit niedrigem Druck durch beide Kühlmittelanschlüsse geblasen.

Lagerbedingungen:

Temperatur: -10 bis +40 °C
Luftfeuchtigkeit: max. 95 %

Transportbedingungen

Temperatur: -10 bis +70 °C
Luftfeuchtigkeit: max. 95 %

Storage and Transportation

General

After switching off the high voltage, discharge the cables and the high voltage capacitors of the generator by connecting the conductors with ground potential to ensure that the cables can be touched without danger.

Use original or an equivalent packaging for storage and transport of tubes and tube assemblies.

For transportion cover the high voltage receptacle sockets with the two plastic covers included at delivery. This is to ensure cleanliness of the high voltage receptacle sockets.

If the unit is not in use for a long period of time, residual coolant should be removed from the cooling system. For this purpose blow compressed air through both inlet fittings for a few seconds.

Storage Conditions

Temperature: -10 to +40 °C at max. 95 % humidity

Transportation Conditions

Temperature: -10 to +70 °C at max. 95 % humidity

Rücksendung an COMET

Vor der Rücksendung an COMET ist eine Rücksendungsnummer (RGA-Nummer) zu verlangen. Benützen Sie dazu das mitgelieferte RGA-Formular oder kontaktieren Sie COMET.

Das RGA-Formular und der ausgefüllte Feldausfallrapport (Field Failure Report) sind den Versanddokumenten beizulegen.

Bei Rücksendung zur Entsorgung ist auf den Versanddokumenten der Vermerk "ZUR ENTSORGUNG" anzubringen.

Return of Goods to COMET

Prior to shipment to COMET a Returned Goods Authorisation No. will be required. Please use the RGA form supplied at delivery or contact COMET.

The RGA form and the completed Field Failure Report should be added to the shipping documents.

In case of shipment to COMET for disposal, the shipping documents must be marked with "FOR DISPOSAL".