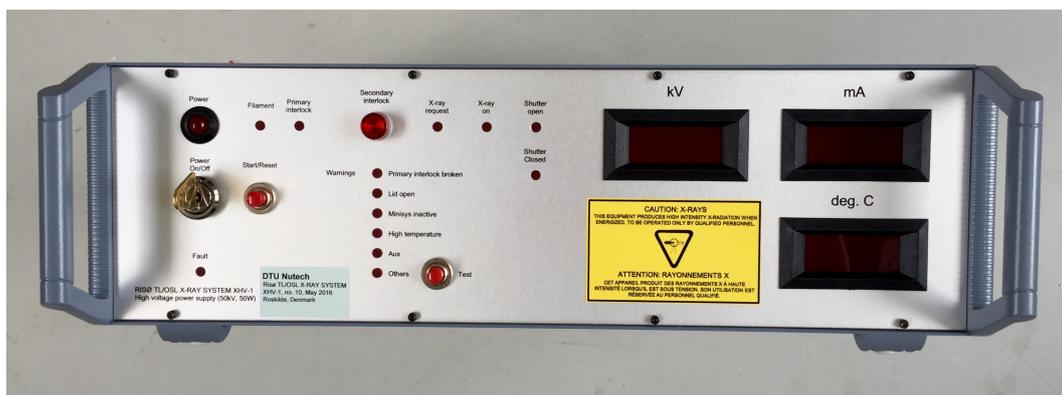


Guide to the Risø XHV-1 x-ray unit



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Chapter 1

Introduction

This is a guide to the Risø XHV-1 x-ray unit designed for use on the Risø TL/OSL reader, Model DA-20. The guide explains the main features of the unit and how to operate, commission, and service it.

1.1 Main health hazards

Note that when the XHV-1 is used with a DA-20 TL/OSL reader, then the whole system should be viewed as a closed-cabinet x-ray system. Any service or non-trivial modifications of the system should therefore be carried out only by personnel authorized to service or modify x-ray equipment.

The main health hazards are as follows:

- Radiation. The dose-rate at the sample position immediately below the tube can reach up to 2 Gy/s. The leakage radiation 5 cm from any accessible external surface on the cabinet of the x-ray unit is below 2 $\mu\text{Sv/h}$ (i.e. below 0.2 milliroentgen pr. hour = 0.2 mR/h) at all times.
- Electrical shock from high voltage. The system applies up to 50 kV 1 mA DC.
- Beryllium. The Varian VF-50 tube contains a 0.076 mm Beryllium-window. Beryllium can be toxic if improperly handled; avoid any contact with the beryllium window.

1.2 System elements

The Risø XHV-1 x-ray unit consists of:

- a shielded, air-cooled Varian VF-50J(W) industrial x-ray tube with Wolfram target.
- a Spellman high-voltage power-supply (a modified version of the 50 kV, 50 W XRM50P50 model with filament preheat and 2 mA maximum current).
- shielding, cooling, and interlock features installed on the Risø TL/OSL Model DA-20.
- control electronics and low-voltage power supplies.

1.3 Main features

The main features of the unit are:

- High-voltage range from ~ 4 to 50 kV.
- Maximum power: 50 W.
- Maximum current: 2 mA within the 50 W-limit. Hence, the units can deliver, for example:
 - 1 mA at 50 kV (as $1 \text{ mA} \times 50 \text{ kV} = 50 \text{ W}$).
 - 2 mA at 25 kV (as $2 \text{ mA} \times 25 \text{ kV} = 50 \text{ W}$).
 - 2 mA at 10 kV (as $2 \text{ mA} \times 25 \text{ kV} \leq 50 \text{ W}$).
- Mechanical shutter.
- Key-controlled on/off switch.
- Two independent interlock systems.
- The primary interlock system uses two dedicated safety relays (Pilz, PNOZ X5) enabling (1) full emergency stop and (2) that the unit does not start automatically after power off or system faults.
- Indicators for system status (including beam on and shutter status) and numerical displays of actual voltage, current and tube temperature.
- Analog outputs (BNC connectors) for external monitoring of control signals (0–10 V) of voltage and current.
- 24V outputs for external warning indicators (lamp and horn/buzzer).
- The leakage radiation 5 cm from any accessible external surface on the cabinet of the x-ray unit is below $2 \mu\text{Sv/h}$ (i.e. below 0.2 milliroentgen pr. hour = 0.2 mR/h) at all times.

Chapter 2

Design and construction

The basic design and function is described in the paper *A mini x-ray generator as an alternative to a $^{90}\text{Sr}^{90}\text{Y}$ beta source in luminescence dating*, by C.E. Andersen, L. Bøtter-Jensen, and A.S. Murray (Radiation Measurements 37 (2003) 557–561).

The x-ray irradiator is a filament type x-ray: Varian VF-50J x-ray tube (50 kV, 1 mA, 50 W) with tungsten target and a 4–50 kV DC Spellman high voltage power. The tube has integral shielding (provided by the manufacturer) and the beam is emitted through a 76 μm thick 8 mm diameter Be window. The tube is cooled by forced-air convection. The power supply is specified to have a 0.05% stability per 8 h (after 1–2 h warm up) and a temperature coefficient of 0.01% per $^{\circ}\text{C}$.

The tube is mounted on a 35 mm long brass collimator (internal diameter 10 mm) with a 50 μm Al end window at the exit. A 7 mm thick mechanical shutter made of stainless steel is positioned within the length of the collimator to prevent the sample from being irradiated until the x-ray output has stabilized.

At the end of an irradiation the shutter is closed before the x-ray is switched off. It takes the shutter 62 ms to open and 145 ms to close. Thus, the actual irradiation time is about 80 ms longer than the programmed time. The distance from the face of the x-ray tube to the sample is 35.5 mm, and the average dose rate at 50 kV and 1 mA (maximum power) to quartz grains mounted on stainless steel discs is approximately 2 Gy/s.

Request for x-ray irradiation are made using the standard Risø sequence editor software giving full control of the irradiation time, the tube voltage and current.

2.1 Generation of x-rays

X-rays arise as the accelerated electrons hit the tungsten target. The maximum potential is 50 kV and the maximum current at that potential is 1 mA. The beam is DC (not pulsed).

The energy spectrum of the x-rays consists of bremsstrahlung and characteristic L-shell x-rays at about 9 keV (i.e. monoenergetic peaks). The spectrum does not contain any characteristic K-shell x-rays, because these lie above 50 keV for tungsten. The bremsstrahlung spectrum extends from zero to E_{max} , where E_{max} is the kinetic energy of the electrons hitting the target (i.e. 50 keV for a potential of 50 kV). Using Kramers equation for a thick target, we calculate the mean energy (weighted by the radiant energy spectrum) for the unfiltered bremsstrahlung continuum to be $E_{\text{max}}/3$, i.e., about 17 keV for a potential of 50 kV.



Figure 2.1: The Varian VF-50 X-ray tube before assembly.

We obtain a somewhat higher result if we apply the empirical spectral models that include both bremsstrahlung and characteristic x-rays. For example, we estimate the mean energy of a 40 kV spectrum to be 19 keV. Filtration caused by the target and the Be and Al windows removes photons with energies below a few keV and thus increases the mean energy. This is desirable since low-energy photons have a reduced ability to penetrate the sample under irradiation; i.e. they will contribute to a depth-dependent irradiation of the sample. With additional filtration, it is possible to further harden the spectrum, at the cost of reducing the dose rate (see *Luminescence response to irradiation using mini x-ray generators* by K.J. Thomsen, L. Bøtter-Jensen, P.M. Denby, A.S. Murray, A.S. (Nuclear Instruments and Methods B, 2006, Volume 252, pp. 267–275).

The total (unfiltered) radiant energy from the bremsstrahlung is proportional to $E_{\max}^2 \times I_T$, where I_T is the tube current. Hence, the dose rate can be changed by adjusting the tube potential as well as the tube current. Changing the tube current is normally preferable as it does not affect the energy spectrum of the x-rays.

Fig. 2.1 shows x-ray tube before assembly. Fig. 2.2 shows the tube in its holder with the forced-air cooling on a test rig at DTU Nutech, and Fig. 2.3 shows the tube during leakage verification measurements.

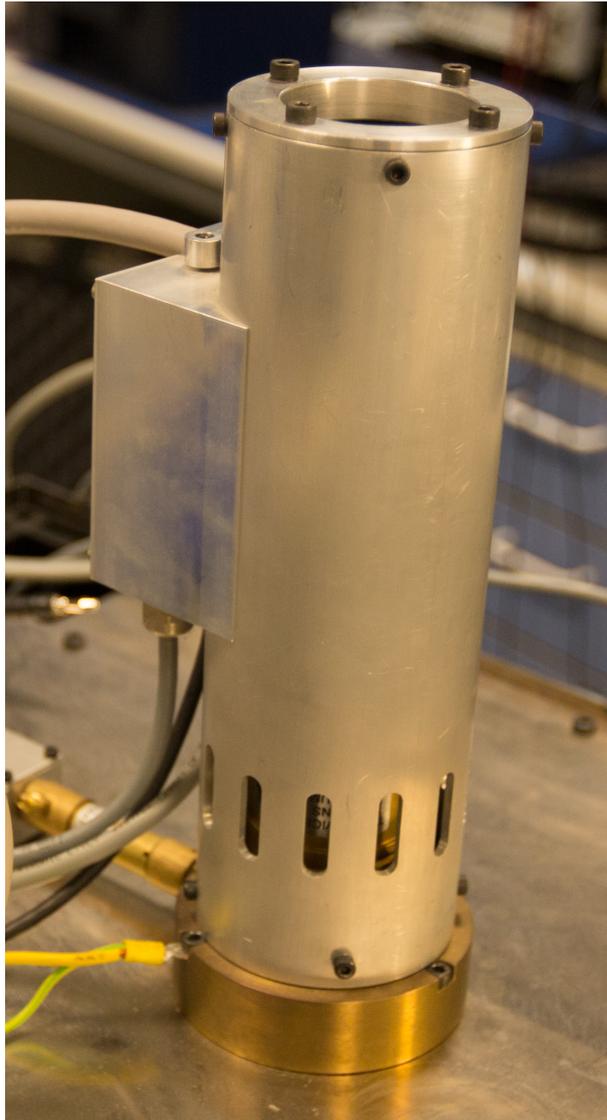


Figure 2.2: The x-ray tube during testing at DTU Nutech.



Figure 2.3: The x-ray tube during leakage testing.

2.2 Radiation protection and safety

2.2.1 Safety system block diagram

A block diagram with all components in the safety design is shown in Figure 6.1 after page 32. Chapter 2.3 provides specific details about all indicators and controls.

The system is designed with certified safety relays for the primary interlock and the supply of power. The system has the following main safety features:

- The system cannot be powered up without manual operation (one needs to turn the key and press the start/reset button).
- The system cannot give x-rays unless both the primary and the secondary interlock systems are closed.
- If any of the two interlock systems are opened while irradiating, the system will go into fault status as this is an indication that someone challenged the system in an uncontrolled way.
- The system also goes into fault mode, if the tube gets too warm.
- The system cannot recover from the fault mode unless the whole unit is powered down and the start/reset button is pressed.
- The system cannot provide x-ray immediately after power-up because of a forced delay of about 5 s.
- The system includes a forced delay between the request for x-rays and the time when the x-rays will start. This allows for warning signals to appear before the irradiation starts.
- The set-points for kV and mA are grounded unless the control signals are above a given threshold.

2.2.2 Key controlled on/off switch

The XHV-1 has a key controlled on/off switch of the mains. If the system is locked in the off position, the unit cannot give x-rays and no power is supplied to the high-voltage unit or other circuits in the XHV-1 control box.

2.2.3 Emergency stop

The XHV-1 has an emergency stop as shown in Fig. 2.4. Activating this emergency stop immediately removes all power from the high-voltage power supply and the x-ray tube. The system cannot recover after an emergency stop without full power-down of the XHV-1 and the start/reset button also has to be pressed manually.

2.2.4 Primary interlock system

The primary interlock tests that the lid of the Risø TL/OSL Model DA-20 is closed. It is not possible to perform x-ray irradiations with the unit unless the primary interlock is un-broken. The primary interlock has been designed using special safety-relays. The primary interlock is thus fully independent of the Spellman power supply, the Risø



Figure 2.4: The x-ray emergency stop.

reader or the DA-20 TL/OSL reader controller (MiniSys). The primary interlock is placed on the side of the lid as shown in Figure 2.5.



Figure 2.5: The primary interlock.

2.2.5 Secondary interlock system

A secondary interlock tests that (1) the lid of the Risø TL/OSL Model DA-20 is closed using sensors mounted inside the reader, (2) that the DA-20 TL/OSL reader controller (MiniSys) is active, and (3) that the tube temperature is below 50°C (indicating the cooling fan is working properly). The indicator for the unbroken secondary interlock is a light-bulb that itself is part of the interlock chain. The secondary interlock uses features of the Spellman power supply, the Risø reader and the DA-20 TL/OSL reader controller (MiniSys).

2.2.6 External warning lamp and indicators

As shown in Fig.2.6, the XHV-1 control box has a set of indicator LEDs on the front panel. These show the status of the system as described in section 2.3. There is also a light bulb on the front panel (called "Secondary interlock") which is part of the secondary interlock system (i.e. it also acts as a fuse, so the system cannot give x-rays if this light bulb breaks). This light bulb indicates that the system is ready and that x-rays can be emitted anytime the user requests to start an irradiation.

The XHV-1 comes with an external warning light connected to the system by cable. However, this warning light is normally not required since this is a closed-cabinet x-ray system.



Figure 2.6: Indicators with status information on the front of the XHV-1 control box.

2.2.7 Grounding

The unit must remain grounded at all times.

2.2.8 Leakage

It is important that the x-ray unit remains intact and that leakage is measured with appropriate health-physics instrumentation. Verification that the leakage is low is established during the production at DTU Nutech, during installation at the user site (commissioning) and annually or with a frequency as required by the local regulations. See Chapter 6.

2.2.9 Shielding design

The collimator block and all shielding components are made of brass.

The x-ray tube is placed in a collimator block (Figure 2.7). The collimator has a sub-mm Al-foil window (Figure 2.8), and is placed on top of the Risø TL/OSL Model

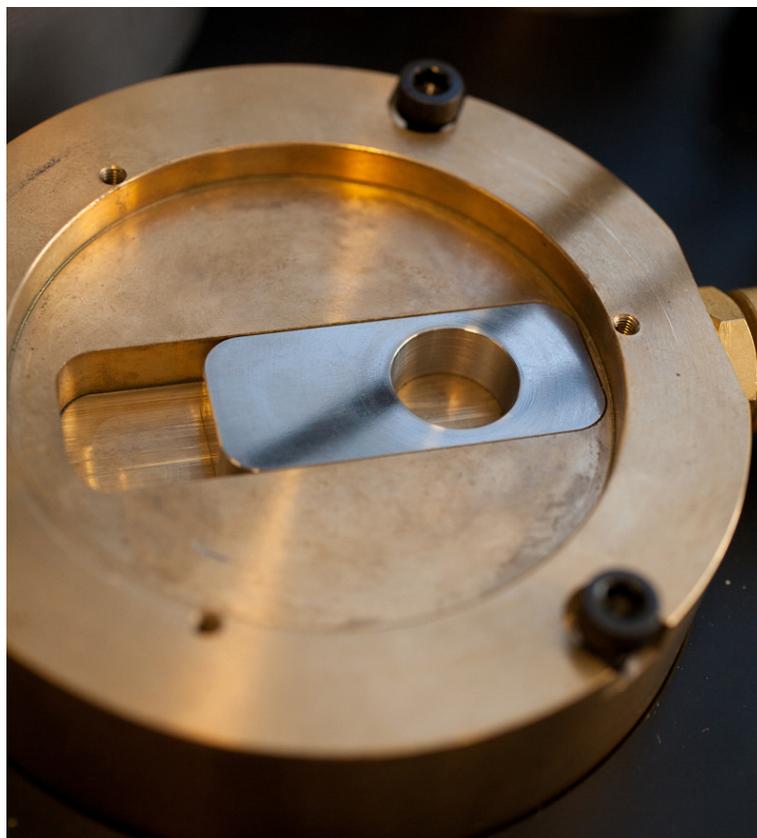


Figure 2.7: The x-ray collimator block with mechanical shutter.

DA-20 (Figure 2.9). A beam-stop is placed below the sample plate (Figure 2.10), and the Risø is equipped with additional shielding at the sides (Figure 2.11).



Figure 2.8: The x-ray collimator window.



Figure 2.9: The x-ray tube is mounted at this position.

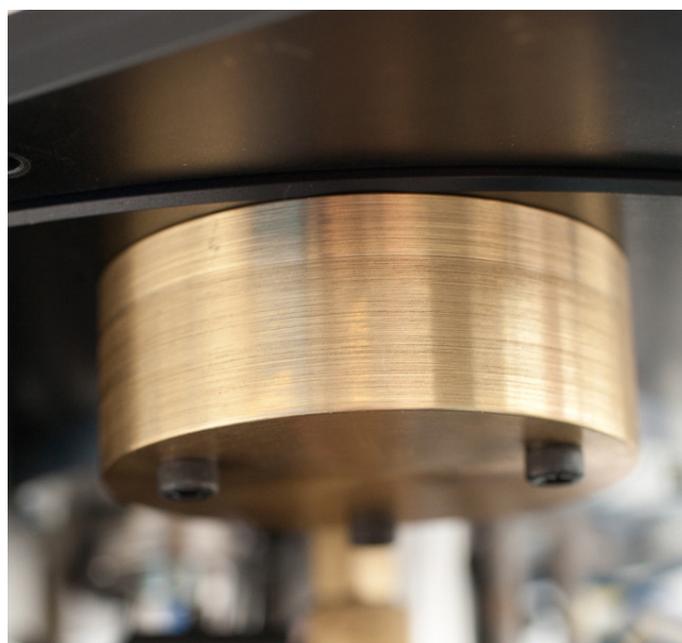


Figure 2.10: The beam stop below the x-ray collimator (shielding removed).

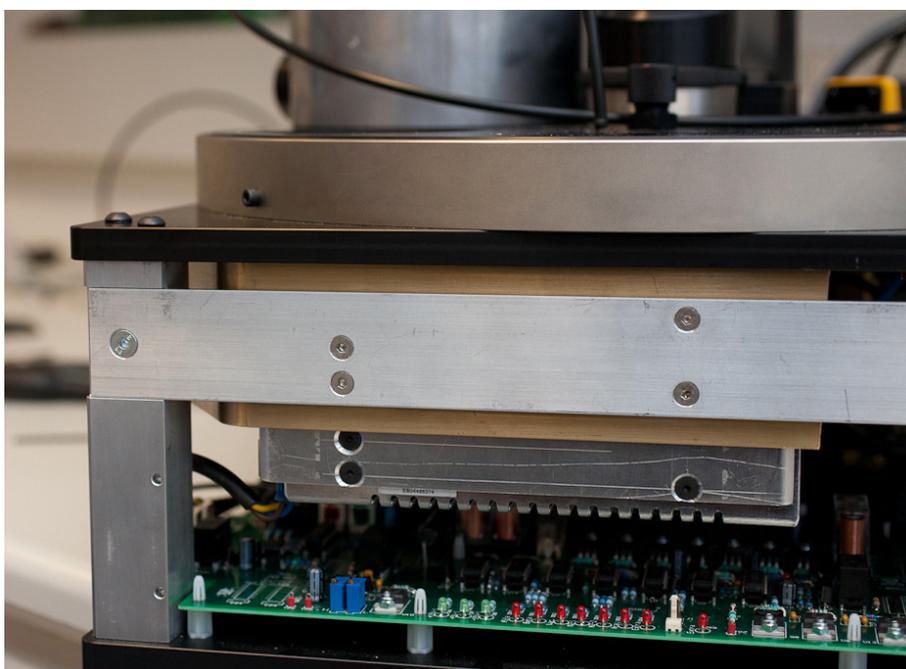


Figure 2.11: Details of the x-ray shielding.

2.2.10 Labels

The back of the XHV-1 unit has labels identifying the main cables with high voltage as shown in Fig. 2.12. The manufacture of the unit (DTU Nutech) is labelled as shown in Fig. 2.13, and an x-ray warning label (such as the one shown in Fig. 2.14), is put on the front of the unit in accordance with local regulations.



Figure 2.12: Labels on the back of the XHV-1 control unit.

DTU Nutech
 Risø TL/OSL X-RAY SYSTEM
 XHV-1, no. 10, May 2016
 Roskilde, Denmark

Figure 2.13: Label (example) with identification of the manufacturer and the unit.

CAUTION: X-RAYS

THIS EQUIPMENT PRODUCES HIGH INTENSITY X-RADIATION WHEN ENERGIZED. TO BE OPERATED ONLY BY QUALIFIED PERSONNEL.



ATTENTION: RAYONNEMENTS X

CET APPAREIL PRODUIT DES RAYONNEMENTS X À HAUTE INTENSITÉ LORSQU'IL EST SOUS TENSION. SON UTILISATION EST RÉSERVÉE AU PERSONNEL QUALIFIÉ.

Figure 2.14: X-ray warning label.

2.3 Indicators and controls

2.3.1 Front panel

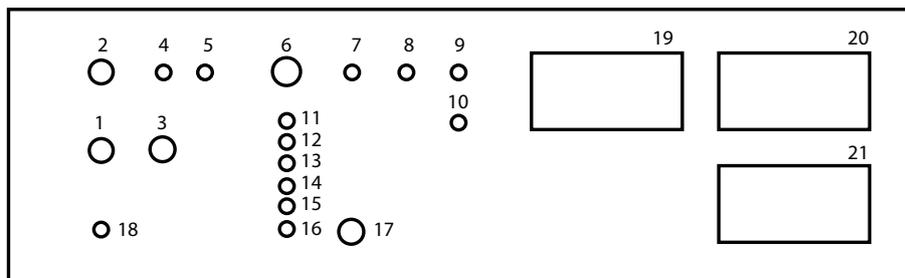


Figure 2.15: Front panel.

1. **Power on/off** Key-controlled on/off switch. The x-ray unit is without any connection to the mains, if this switch is in the off position.
2. **Power** Mains indicator.
3. **Start/reset** Press this switch to activate the safety relays. After power-off, the unit always needs to be activated manually.
4. **Filament** This LED indicates that the filament is on.
5. **Primary interlock** This LED lights if the primary interlock is unbroken (i.e. the Risø TL/OSL Model DA-20 lid is closed). The primary interlock functions using special safety relays.
6. **Secondary interlock** This light-bulb lights if the secondary interlock is unbroken. This means that the high-voltage power supply is energized. The light-bulb itself is part of the interlock and the unit can therefore not be energized if this light-bulb breaks. In other words, the light-bulb also acts as a fuse.
7. **X-ray request** This LED indicates that the control signals for either mA or kV are above zero. In other words: the unit is requested to deliver x-rays.
8. **X-ray on** This LED indicates that the monitor signals for either mA or kV are above zero. In other words: the unit is delivering x-rays.
9. **Shutter open** The mechanical shutter to the sample below the x-ray tube is open (i.e. a sample can be irradiated).
10. **Shutter closed** The mechanical shutter to the sample below the x-ray tube is closed (i.e. no irradiation of samples even if the x-ray tube is on).
11. **Primary interlock broken** This LED gives the warning that the primary interlock is broken.
12. **Lid open** This LED gives the warning that the lid of the Risø TL/OSL Model DA-20 lid is open.

- 13. MiniSys inactive** This LED gives the warning that there appears not to be contact with the DA-20 TL/OSL controller (MiniSys) (this is an electronic watch dog).
- 14. High-temperature** This LED gives the warning that the x-ray temperature is too high. The threshold is 50°C.
- 15. Aux.** This LED gives the warning that the auxiliary interlock is broken. By default this is not used.
- 16. Others** This LED gives the warning that any other interlock are broken.
- 17. Test** This test button is part of the secondary interlock. Press this button to test the interlock system.
- 18. Fault** This LED indicates that a critical fault event has occurred. A critical fault is, for example, that the interlock was broken while x-rays are requested (i.e. the kV or mA set points are above zero volts) or while the x-ray tube is actually irradiating (i.e. the kV or mA monitor signals are above zero volts). The x-ray unit goes in power-off mode after a critical fault. The units need to be completely powered off with the keys (1) and manually reset (3).
- 19. kV** This indicator shows the actual voltage of the x-ray tube (kV monitor signal).
- 20. mA** This indicator shows the actual current of the x-ray tube (mA monitor signal).
- 21. degC** This indicator shows the actual temperature of the x-ray tube. The temperature sensor is placed on the cooling fins at the top part of the tube housing.

2.3.2 Back panel

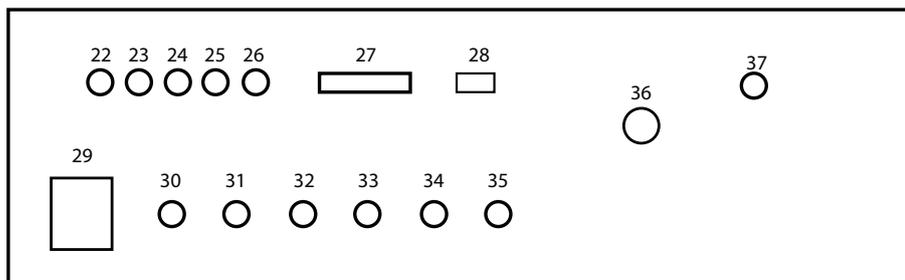


Figure 2.16: Back panel.

- 22. Temperature** BNC voltage output proportional to the the x-ray tube temperature: 23.5 °C equals 0.235 V etc.
- 23. Set-point kV** BNC voltage output (0–10 V) proportional with the set-point for the x-ray tube potential: 50 kV equals 10 V, 25 kV equals 5 V etc.
- 24. Set-point mA** BNC voltage output (0–10 V) proportional with the set-point for the x-ray tube current: 2 mA equals 10 V, 1 mA equals 5 V etc.
- 25. Monitor kV** BNC voltage output (0–10 V) proportional with the actual x-ray tube potential: 50 kV equals 10 V, 25 kV equals 5 V etc.

26. **Monitor mA** BNC voltage output (0–10 V) proportional with the actual x-ray tube current: 2 mA equals 10 V, 1 mA equals 5 V etc.
27. **MiniSys** Connector to the DA-20 TL/OSL reader controller (MiniSys).
28. **Control box** Connector to the control box.
29. **Mains 110–240V AC** Mains input and fuse.
30. **External lamp/horn** Connector for external x-ray indicators: One relay-driven lamp output (24 V max 1 A) and one horn/buzzer output (open-collector power transistor; 24 V max 0.1 A).
31. **PMT/AUX** Connector to supplementary elements that should be interlocked.
32. **Primary interlock** Connector to the primary interlock.
33. **Emergency stop** Connector to the emergency stop.
34. **Shutter / Temp.** Connector to the mechanical shutter and the x-ray temperature.
35. **Filament bias** Connector to the filament bias.
36. **50 kilovolts** High-voltage cable.
37. **Ground.** Secure chassis ground contact.

2.4 Manufacturer quality assurance (QA) testing procedures

The following quality assurance (QA) testing procedures are applied by DTU Nutech:

- The control electronics produced by DTU Nutech is tested using simulated signals (i.e. without any x-ray source).
- The x-ray tube is tested by Varian, and the high-voltage power supply is tested by Spellman before the XHV-1 is assembled at DTU Nutech.
- After assembly, the functioning is tested at DTU Nutech using a DA-20 TL/OSL reader without any beta source. Safety procedures and leakage measurements are carried out using procedures similar to those described in the commissioning section of this guide. The testing procedures at DTU Nutech, however, normally extend over longer periods of time (1–2 days).
- It is tested that the XHV-1's three electronic displays showing kV, mA and temperature are in agreement with measurement carried out using independent measurements.

Chapter 3

Installation

3.1 Positioning

The DTU Nutech installer places the XHV-1 control box on a mechanically stable and dry laboratory desk adjacent to the DA-20 TL/OSL reader instrument. Recommended bench space of at least 90 cm. The full unit weighs 80–90 kg.

3.2 Cables

The installer makes all cable connections between the tube on the DA-20 TL/OSL reader and the XHV-1 control box. The main high-voltage cable requires that the control box is opened. The cable is screwed-locked onto the Spellman high-voltage power-supply.

A dedicated grounding cable is attached to the "Secure chassis ground" (item 37 in Fig. 2.16) and the x-ray tube collimator head on the DA-20 TL/OSL reader.

The installer connects item 30–35 in Fig. 2.16 with cables or with dummy plugs. The cables go to the x-ray tube, the emergency stop button, or the lamp.

All cables are labelled and all connectors are uniquely pin-coded such that permutations are not possible. Normally, item 31 (connector for an additional interlock feature) in Fig. 2.16 is not used and this connector is therefore filled with a dummy plug provided by DTU Nutech.

A safety enable loop runs through all cables or dummy plugs connected to item 30–35 in Fig. 2.16. This means that the XHV-1 cannot be powered on if any of these cables or dummy plugs are missing.

All cables (but in particular the thick high-voltage cable) should run in a smooth and controlled way.

3.3 Emergency stop

The emergency stop is positioned in a relevant location. It is recommended that the user fixes the emergency stop permanently to the laboratory table using the dedicated screw holes.

3.4 External warning light

The external warning light is installed in accordance with local regulations and on request of the user. Normally such an external warning light is not required for closed-cabinet x-ray sources such as this system.

3.5 Grounding

The XHV-1 must be securely grounded. This is best done using the dedicated "Secure chassis ground" (item 37 in Fig. 2.16) and a ground connection provided by the user. Alternatively, the XHV-1 is grounded using standard mains cable with grounding.

3.6 Warning labels

Any additional warning labels and signs are placed on the XHV-1 unit or other places in accordance with the requirements from the local authorities.

Chapter 4

Commissioning

4.1 Grounding verification

The installer will need to verify that the grounding is adequate. This is done by measuring the resistance with an ohmmeter between the known ground (identified by the user) and various parts of the XHV-1 such as the chassis and the outer part of the tube mounted on the DA-20 TL/OSL reader. The resistance should be below 1 ohm.

4.2 Emergency stop verification

After power-on, it is tested that activation of the emergency stop completely de-energizes the XHV-1. The unit should go in fault mode when activating the emergency stop.

4.3 Interlock verification

After power-on and without requesting the unit to emit x-rays, press the test button (item 17 on Fig. 2.15) to break the interlock circuit. Since the unit is not irradiating, that is a non-critical break of the interlock circuit (equivalent to opening the lid on the DA-20 TL/OSL reader). The relevant LED (item 16 on Fig. 2.15) will turn red in response to pressing the Test button.

Set the unit to emit x-rays and press the test button. This is a simulation of a critical break of the interlock circuit, and the XHV-1 should go into fault mode. In fault mode, the XHV-1 is de-energized, and the fault LED (item 18 on Fig. 2.15) will turn red. The XHV-1 cannot come out of the fault mode unless the mains is removed (i.e. turn the key; item 1 on Fig. 2.15) and manually press the start/reset button (item 3 on Fig. 2.15).

4.4 Display verification

After power-on, the display indicators should show about 0 kV 0 mA and a temperature slightly above room temperature.

The installer verifies consistency between the kV and the mA display and the requested set-points. At least the following settings are tested:

- 10 kV 0.1 mA

- 20 kV 0.1 mA
- 30 kV 0.5 mA
- 50 kV 1 mA

The agreement should be within 5%.

A defect x-ray tube can sometimes be identified from a significant discrepancy between the requested set-point as given by the DA-20 TL/OSL sequencer command and the voltage shown on the kV / mA display.

The DTU Nutech installer may measure the actual setpoints (analog voltages) using the dedicated BNC connectors and a voltmeter (see item 23 to 26 on Fig. 2.16).

4.5 Dose uniformity verification

A small piece of EBT-3 Gafchromic film is placed in the sample wheel of the DA-20 TL/OSL reader and the installer irradiates for 20 s at 50 kV and 0.2 mA. The film should show a uniform dark colouring.

4.6 Dose rate measurement

The maximum dose rate to a sample of quartz is recorded at 50 kV and 1 mA.

4.7 Leakage radiation assessment

The system is designed such that the leakage radiation 5 cm from any accessible external surface on the cabinet of the x-ray unit is below $2 \mu\text{Sv/h}$ (i.e. below 0.2 milliroentgen pr. hour) at all times. During transport or service, the shielding could in principle be damaged, and the leakage could increase. The leakage radiation should therefore be verified after initial installation.

An initial or supplementary qualitative survey can be carried out using, for example, a thin-window Geiger counter device.

The low-leakage rate is best verified in the absence of any radioactive beta source on the DA-20 TL/OSL reader using a suitable health-physics survey meter such as the Thermo Fischer Scientific Micro Rem/Sievert Tissue-Equivalent Survey Meter. If the beta source is present, then it should be verified that there is no change in leakage when the XHV-1 is set to deliver x-rays at the maximum dose rate both with and without the shutter closed, and both with or without a steel sample disc in the irradiation position.

Verification of the low-leakage dose rate is subject to a high uncertainty if carried out in the presence of a beta source on the DA-20 TL/OSL reader.

The leakage radiation assessment is best carried out by the installer in collaboration with the user and the local radiation protection officer.

Recall to measure also below DA-20 TL/OSL reader if that area is accessible.

Chapter 5

Operation

5.1 Basic operation

- Turn the key.
- Press the start/reset button.
- Put the sample to be irradiated in the DA-20 TL/OSL reader.
- Program the sequence editor as explained below for x-ray irradiation.
- After use, it is best to let the XHV-1 run for 10 min without giving x-rays as to cool down the x-ray tube. This is because the forced-air cooling is powered from the XHV-1 unit. So, if the XHV-1 is off, then there is no cooling of the tube.

5.2 Warm-up

To extend the life-time of the x-ray tube, it is recommended that the tube is warmed up as given in Table 5.1. In particular, this procedure is recommended when the tube has not been used for a long time (weeks). The easiest way execute the warm-up procedure is to run a dedicated sequence (see `xraywarmup.seq` in the `samples` directory).

Table 5.1: Warm-up procedure.

Voltage kV	Current mA	Time min
10	0.15	5
15	0.15	5
20	0.30	5
25	0.60	5
30	1.0	5
35	1.0	5
40	1.0	5
45	1.0	5
50	1.0	5

5.3 X-ray commands for the DA-20 TL/OSL controller (MiniSys)

The x-ray unit is controlled from the DA-20 TL/OSL controller (MiniSys) using the following commands (consult the TL-OSL command list document; version 3.15 or later):

Table 5.2: List of MiniSys commands.

Command	Text
XC	Cancel x-ray irradiation.
XI [t]	X-ray irradiation for t seconds.
XP p	Move sample p to the x-ray irradiator.
SX v i	Set voltage (v) in kV and current (i) in mA.

Chapter 6

Preventive maintenance checks and service

6.1 User-driven service checks

It is recommended that the following procedure is carried out at least annually by the user in collaboration with the local radiation officer:

- Ascertain that the XVH-1 is positioned in a stable and dry position, and that there are no loose screws or damage of the enclosure or other components relevant for the safety features or the shielding.
- Ascertain that all cables run smoothly (i.e. avoid sharp bends).
- Inspect cables for any signs of damage that could compromise the insulation or the functioning of the cables.
- Consider if the noise level from the cooling fan has changed. An increased noise level could indicate that the fan needs replacement.
- Test the emergency stop and the interlock system as explained in the commissioning section of this guide.
- Verify that indicators and warning lights are working properly.
- Verify that the leakage radiation is below $2 \mu\text{Sv/h}$.

To extend the lifetime of the x-ray tube it is recommended that the unit is used at least once every two months.

6.2 Repair and service

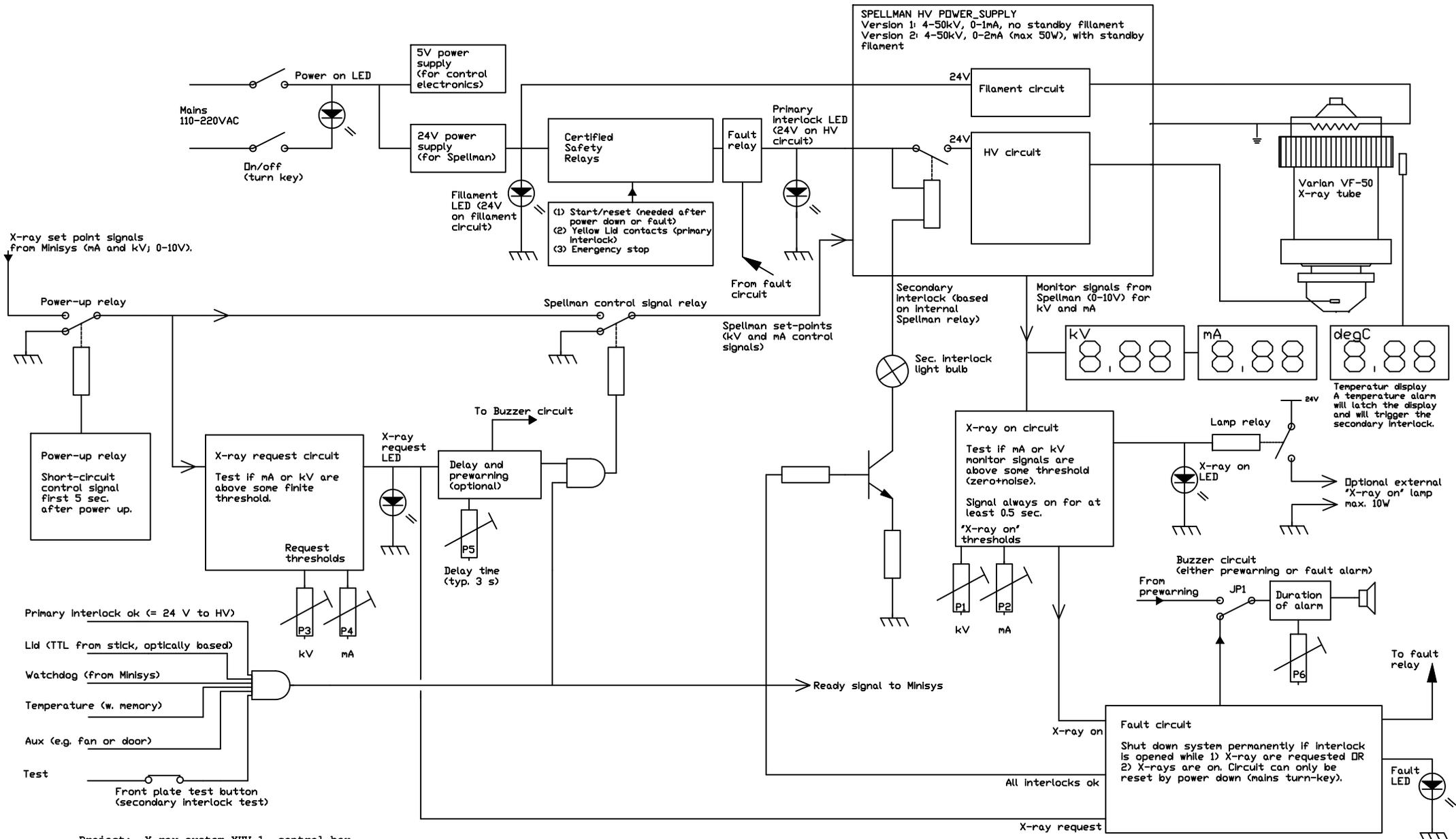
Service should be carried out only by personnel authorized for servicing x-ray equipment. Consult DTU Nutech in case of questions.

6.3 Disposal of the product

At the end of the product life, the components must be disposed of in compliance with the local waste control regulations.

The Varian VF-50 tube contains a Be-window. This should be handled as toxic material.

Figure 6.1: (see next page) Block diagram (mainly for internal use by DTU Nutech) outlining the various components of the system.



Project: X-ray system XHV-1, control box
 Drawing: System overview
 File: xray-function017.dwg
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 Revised: January 30, 2008
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